IDENTIFYING, TRACKING, AND PRIORITIZING PARTS UNAVAILABILITY

THESIS

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THESIS

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Abstract

The Air Force is pursuing several efficiency initiatives designed to reduce support function costs. One such initiative is an effort to reduce the flow days of items being repaired in the Air Force's organic depots. Many end items are affected by awaiting parts (AWP) delays, which increase total flow days. The first step in reducing AWP delays is to identify which piece parts are causing the delays.

A gap analysis was conducted to identify a process for creating a list of piece parts that are causing AWP delays. In addition, a clinimetric method was used to develop an aggregate measure of AWP impact by which the list of piece parts could be prioritized. The gap analysis showed that such a list can be created with Cognos, a reporting tool currently used by the depots, which can pull data from multiple information systems. In addition, only minor changes to information recorded throughout the repair process are needed. An aggregate measure of AWP impact was also created and tested. It produced significantly different prioritizations from the individual constituent variables, and provides a possible method for helping depot managers to understand decision tradeoffs between different parts shortage priorities.

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I. Introduction

1.1   Background

The Air Force's organic depots suffer from increased flow days due to awaiting

parts (AWP). In fiscal year 2012, the 76th Commodities Maintenance Group experienced

more than 505,000 AWP days across 479 end items. Reducing AWP time on end items

being repaired would reduce the total shop flow days and inventory costs. The Air Force

recently undertook several efficiency initiatives to reduce overhead and support function

costs (Department of Defense, 2011). One of those initiatives was to reduce costs in

Logistics and Infrastructure, specifically through Supply Chain Management (SCM)

efficiencies. This includes a concerted effort to reduce the flow days of items being

repaired in the Air Force's organic depots (Frickson, 2012). Many process improvement

efforts have yielded outstanding initial results, and AWP time reduction is an extension

of this effort.

Reducing flow days is an effective means of reducing costs through inventory

reductions. This concept is based on Little's Law, which shows that the amount of

inventory in a depot is a product of flow time and flow rate (Little, 1961: 383).

Therefore, if the flow time (shop flow days in this case) is reduced, inventory in the depot

will be reduced. In addition to cost savings, reducing flow days increases the

responsiveness of the depots by repairing end items faster. The problem of AWP time is

not new. It represents a classic tradeoff between inventory cost and responsiveness to the

customer (the warfighter). Massive amounts of inventory can be held to ensure that parts

are available for end item repairs when and where needed, which ensures the highest

possible responsiveness to warfighter needs. However, this is not a practical solution to

the AWP problem. Such inventory stores would cause support costs to soar and it would

not be sustainable, especially given the current fiscal situation. As a result, the Air Force

must find an appropriate balance between inventory cost and responsiveness to the

warfighter.

1.2 Definitions

For the purposes of this study, "AWP" is meant in the broadest sense. It includes

the formal AWP process used by the Air Force and the Defense Logistics Agency (DLA),

and it includes any situation where an end item is not able to be repaired due to a part(s)

not being physically available to the mechanic. Any exceptions to this definition will be

explicitly stated.

1.3 Problem Statement

To attempt to strike the balance between inventory costs and warfighter needs, the

Air Force uses multiple information systems (ESS, EXPRESS, ABOM, NIMMS, ITS,

D035, D200, etc.) and reams of instructions, policies, and procedures (AFMAN 23-110,

EXPRESS Information Handbook, MAJCOM OIs, ALC OIs, Local OIs, etc.). The

combination of the two creates a fairly automated supply chain. However, despite the

quality of the information systems, instructions, policies, and procedures, there are still

numerous cases of parts not being available when and where they are needed. The 76th Commodities Maintenance Group currently has 615 piece parts backordered against 362 end items. Much effort has been and is still expended on correcting these errors and creating a better supply chain. Regardless of how successful these initiatives have been or will be there will always be incidences where the supply chain fails to provide the right parts, in the right place, in the right quantity, and at the right time. In short, there will always be AWP delays.

The depots can identify which end items are consistently put into the formal AWP process and how long they spend in the process. However, they cannot identify which **parts** consistently **cause** end items to enter the formal AWP process. In addition, they cannot identify which parts consistently cause AWP delays aside from the formal AWP process. The current information systems do not track AWP delays that are projected to be less than 10 days. Finally, the depots do not have a way to prioritize which parts cause the most problems. Therefore, they need a process to identify which parts shortages have the greatest negative impact on their operations. Such a capability would allow the depots to conduct a Pareto analysis to focus problem solving efforts on the worst problems.

This research develops a process for creating a prioritized list of parts that have the greatest negative impact on their operations. The process will allow depots to create a list of which parts are causing AWP delays, which is the first step towards reducing AWP delays in the depots. In addition, this research will develop a measure (metric) of AWP impact. This metric can then be used to prioritize the list of parts by their impact. This can allow the depots to identify to their suppliers which parts are most important for them

to acquire for immediate use, thus increasing responsiveness to the warfighter. It will also allow them to monitor the list over time, so trends may be identified, inventory investments may be justified, or problem solving efforts can be focused. This has the added benefit of providing a feedback loop to Air Force demand planners/forecasters.

1.4   Research Scope

The scope of this research will be limited to end items repaired in the 76th Commodities Maintenance Group at the Oklahoma City Air Logistics Complex. This limitation is necessary given the amount of variation in systems, processes, parts, and procedures across the depots and even within the Oklahoma City Air Logistics Complex. However, this research is intended to provide a template for other units within the Oklahoma City Air Logistics Complex and the other two Air Logistics Complexes.

1.5   Approach

This research consists of two main parts: a gap analysis of the information available and the information needed to create a list of piece parts causing AWP delays; and the development of a measure for prioritizing the parts list. First, it is necessary to determine what information is needed to develop a list of parts causing AWP delays. Then, the information that is available in the current information systems must be identified through process/information mapping of the end items in the repair process. Once the current state and the desired end state are identified as described above, a gap analysis between the two states will be conducted. If no gaps exist, then a process for retrieving and organizing the necessary data will be created. If there are information gaps, then recommendations on how to close those gaps will be developed. Finally, a measurement of AWP impact will be developed. AWP impact cannot be defined except

by the instrument used to measure it. Therefore, this measure will be developed using a pragmatic approach. This will involve combining several observable attributes (manifest variables) in the proper fashion to determine the value of the unobservable attribute (latent variable), which will be called the AWP Impact Index (Hand, 2004: 15, 52, 152).

1.6   Thesis Outline

This thesis consists of five chapters: an introduction, a literature review, an explanation of the research methodology, an explanation of the analysis and research results, and conclusions based on the results. Chapter two contains a review of literature pertaining to the various supply management models the Air Force uses, efforts to address the Air Force's supply chain shortcomings, forecasting principles, and measurement theory. Chapter three describes how the gap analysis was conducted, how information was gathered, and how the AWP Impact Index was developed. Chapter four explains what information was gathered and presents the results of the gap analysis. It also provides a detailed explanation of the development of the AWP Impact Index. Chapter five will recommend a process to close any information gaps identified in chapter four and describe the process by which a prioritized parts list can be created. Finally, it will recommend several methods for prioritizing the parts list.

II.   Literature Review

2.1   Overview

In identifying and analyzing the problem, a review of the literature and Air Force

programs regarding awaiting parts and the overall supply process was conducted. This

included literature on the various models and systems the Air Force uses to manage its

supply chain. In addition, literature pertaining to forecasting principles and Air Force

demand planning, particularly feedback loops, was reviewed to ensure the process

developed could be used as a feedback loop for Air Force demand planners, if desired.

Finally, a literature review of measurement theory was conducted to ensure the AWP

Impact Index development was consistent with existing theory and practices.

2.2   Awaiting Parts Research/Programs

Much research has been done to provide a better model or system to avoid or

minimize AWP delays. Regardless of the quality of a supply chain management model

or system, there will necessarily always be some AWP delays because of the tradeoff

between inventory costs and warfighter needs. The question is how many AWP delays

are acceptable and what should be done to address those delays? An article in the

Journal of Air Force Logistics entitled "Why So Many AWP LRUs?" discusses how the

Air Force seems to consistently have too many line-replaceable units (LRUs) and shop-

replaceable units (SRUs) in formal AWP status. The authors provide a very good

summary of how end items are chosen for repair in the depots:

> The Execution and Prioritization of Repair Support System (EXPRESS) was
> implemented throughout AFMC depots starting in 1995. Its logic prioritizes
> warfighter needs for LRUs to be supplied from the depot component repair
> program. By netting out all LRU repair pipelines, the system determines each day
> what each repair shop should induct. After it determines the prioritized induction

list of LRUs for each shop, it proceeds down the prioritized induction list of LRUs to see if the needed resources are in place to execute the repair of each item on the list. If one of the resources is unavailable, the system skips over that LRU and checks the next item on the list. This process continues down the prioritized list to find any LRU that has all the depot resources to do the repair. That *successful* list is sent to the D035 Express Table for immediate induction into the repair shop. (Carter and London, 2003:31)

The authors further explain why this process is flawed. EXPRESS relies on probabilities to determine which parts are needed. As a result, an end item could be prevented from being repaired due to the unavailability of a part even though that part may not be needed. The parts actually needed are determined when it enters the repair process. In addition, they explain that stock levels are based on historical demand, but many parts are not stocked because they do not have any or much historical demand. This makes sense if historical demand is a good predictor of future demand. The authors argue "historical usage is not a good indicator of the real requirement" (Carter and London, 2003: 31). In addition, even if the historical demand was a good indicator of future demand, the use of probabilities to determine the parts required for repair inherently includes a certain amount of error. This highlights the fact that there will be AWP delays and the depots must be able to respond to those delays in a timely and effective manner.

An additional benefit this article provides is an explanation of the delays created by EXPRESS's induction logic. An end item that is first on the prioritized list of LRUs to be repaired could be inducted behind an end item with a lower priority if all the parts were not available for the higher priority end item. This leads to higher priority items being passed over for lower priority items just because all the parts it *predicts* it will need

are not available. As a result, some end items do not enter the formal AWP system as soon as they should, but are in fact delayed entering the depot repair process due to parts not being available. If the end item does not enter formal AWP status, then it does not receive the extra attention it deserves. While this does not create a delay in the depot, it does delay that end item before it even enters the depot repair process. This delay should be recorded and tracked along with the delays caused once an end item enters the repair process.

A current effort to capture the effect of AWP time and to counter it is called Deep Look. It was started by Defense Logistics Agency at the Ogden Air Logistics Complex, refined, and passed on to the Oklahoma City Air Logistics Complex and the Warner Robins Air Logistics Complex. It was started in 2009 and the Oklahoma City Air Logistics Complex Deep Look Center was stood up in January 2012 (Schwing, 2012). Deep Look addresses the same problem as this thesis, but from the end item perspective. The program develops a prioritized list of end items based on warfighter needs. The members of the Deep Look Center then do a *deep look* using a holistic approach to determine where the problem lies, such as "materials, manpower, equipment, facilities, technical data, etc." (Kinkade et al, 2009: 3).

Deep Look's intent is not to address the AWP problem, specifically. For each end item, there might be several parts that require attention. There is no distinction made between the parts that are needed though. In other words, each part is treated as equally important. From an end item perspective, this is perfectly logical. However, the equal treatment of each part ignores the effect the parts have on other end items. The effect on

multiple end items of one particular part not being available is precisely what this thesis attempts to capture.

2.3   Air Force Supply Chain Models/Systems

The Air Force uses several models and systems to attempt to strike the balance between inventory costs and warfighter needs. Each of these models and systems try to prevent the need for an AWP process. Blazer and Sloan provide an overview of four models the Air Force uses to provide the right parts in the right place at the right time for the right cost. The Aircraft Availability Model (AAM), Aircraft Sustainment Model (ASM), Equipment Prioritization, and Customer-Oriented Leveling Technique (COLT) are the four models discussed. Given a set amount of funding, the Aircraft Availability Model uses marginal analysis to determine which end item should be purchased next. The next best item to purchase is based on how much that item will increase aircraft availability per dollar spent, or based on the most "bang per buck" (Blazer and Sloan, 2007: 68). Its purpose is to ensure that the limited amount of funding available is spent in an optimum manner. This should provide the Air Force the maximum aircraft availability given the budget constraints. However, this model inherently concedes that AWP delays will still occur. The Aircraft Sustainability Model is very similar to Aircraft Availability Model, but its purpose is limited to planning wartime spares requirements. Again, this model aims to prevent AWP delays, but it inherently accepts that some will occur. The Equipment Prioritization Model uses marginal analysis to determine which equipment items to buy given the funding constraints. While the model does not involve buying parts for aircraft, it does show another example of the Air Force attempting to minimize shortages, but accepting that shortages will still occur. Finally, the Customer-

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Oriented Leveling Technique determines stock levels at depots and bases with the objective of minimizing customer wait time. It operates under the same budget constraints as the previous models, but it aims to optimize the quantity and mix of parts at each location (bases and depots). All four of these models attempt to minimize AWP delays and they all accept that AWP delays will still occur because resources are limited. However, none of them address what to do when those delays occur or how to measure the delays because those are not their purposes (Blazer and Sloan, 2007: 68-70).

A report by the Logistics Management Institute further discusses leveling techniques using lean logistics principles. Instead of a total reengineering of Air Force systems and procedures, the report advocates the careful implementation of readiness-based leveling (RBL) in order to complement the D041 system, which calculates the total worldwide spares requirement. Interestingly, the report explicitly discusses the shortages that are expected with the Air Force's various supply chain models. "Lean Logistics focuses more on quick response to parts shortages when they occur rather than on attempting to preclude shortages by investment in large inventories" (O'Malley, 1996: 2). This statement highlights the choice between inventory and responsiveness, and it argues that variability (shortages) should be countered by responsiveness whenever possible. While the report does not advocate removing all Air Force legacy systems, it does state that "their lack of timeliness is an impediment to realizing the benefits of Lean Logistics and must be overcome" (O'Malley, 1996: 2).

For example, the Air Force's current systems and procedures capture and track a parts shortage at the depot if it enters the formal AWP process. However, this is only implemented if an item is estimated to take 10 days or more to acquire (76th Maintenance

Wing, 2012). This creates the possibility of hundreds, if not thousands of days in delays without ever being identified and tracked. The 10-day standard for entry into the formal AWP process is intended to limit the end items in formal AWP status to only those that are expected to experience severe delays. In this case, the Defense Logistics Agency has defined "severe" as 10 days or more (76th Maintenance Wing, 2012). However, this standard ignores the aggregate impact of small AWP delays and it hides the small delays in daily activities, making them difficult to address. In addition, some units do not have a formal AWP process, such as the 76th Propulsion Maintenance Group. Also, the formal AWP process is inconsistently applied, such as waiting 30 days to enter an end item into formal AWP status (see section 4.3). These examples show that some AWP delays are not immediately identified, if at all, or actively tracked. If a delay is not identified, the supply chain cannot respond to it. This is not to say, the Air Force does not respond to parts shortages at all. However, it does not adequately identify, track, prioritize, and respond to all parts shortages. According to Womack and Jones in their book *Lean Thinking*, "transparency in everything is a key principle" (Womack and Jones, 2003: 97). In other words, lean principles dictate that any delay should be given immediate attention and be aggressively attacked. Currently, the Air Force lacks the full awareness and level of detail necessary to even have the opportunity to respond to such delays. This research aims to provide the Air Force with such opportunities.

2.4   Forecasting Principles and Air Force Demand Planning

A brief discussion of forecasting principles is appropriate for two reasons. First, as demonstrated in the previous section, the Air Force has invested much time and money to develop a robust supply chain, to include a forecasting process. Second, one of the

intents of this research is to develop a feedback loop that might be useful to forecasters. *Business Forecasting*, written by J. Holton Wilson and Barry Keating, discusses a 9 step forecasting process. Their ninth step is "Tracking Results." They state that "Deviations from the forecast and the actual events should be discussed in an open, objective, and positive manner" (Wilson and Keating, 2009: 490). This is consistent with lean principles as well. The authors go on to explain that these discussions need to be for the purpose of improving future forecasts. An understanding of why the actual data deviates from the forecasts is necessary. In addition, one must determine if the size of the deviation is significant enough to warrant changes to the model or the forecasting process (Wilson and Keating, 2009: 490-491). The point being made by the authors is that feedback on the quality and accuracy of the forecast is not only useful, but essential to determining the validity of the forecasting model/process.

The source of feedback also matters. "It is important to stress…the critical role that communication and cooperation between managers and technicians play in building and maintaining a successful forecasting process" (Wilson and Keating, 2009: 491). The commitment to communication is also critical because a forecast model's validity can and most likely will change over time. Again, the quality of the Air Force's forecasting models is not in question, but proper validation of them through continuous feedback is absolutely necessary. The formal AWP process does not provide full feedback to the Air Force's demand planners. In addition, some units do not have a formal AWP process, such as the 76th Propulsion Maintenance Group. As a result, the full "magnitude of the errors" cannot be determined, which does not allow for a proper assessment of the forecasting model (Wilson and Keating, 2009: 490).

The primary forecasting model used by the Air Force is the Reparability Forecast Model (RFM). The RFM operates similar to a Material Requirements Planning (MRP) system, where it takes inputs from various systems that tell it what parts are needed, when they are needed, how long it takes to get them, and if the parts are in stock. The output is a report showing what the consumable shortfalls are, as depicted in Figure 1 (Gaudette et al, 2002: 7).
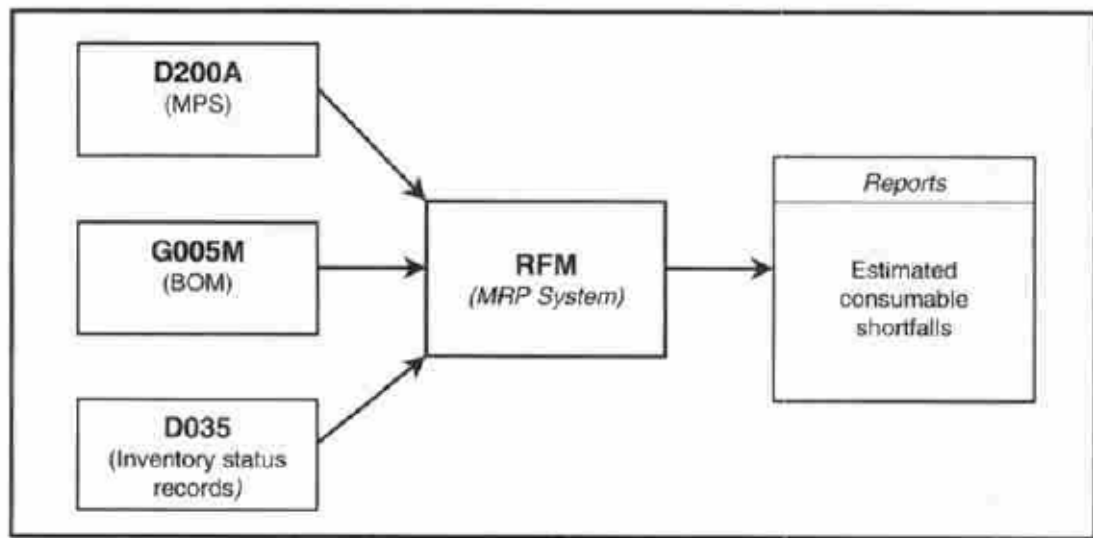
Figure 1. Inputs and Outputs of RFM with MRP Equivalents in Parentheses (Gaudette et al, 2002: 7)

The Reparability Forecast Model does not determine stock levels or conduct any ordering. It simply forecasts the need based on projected repairs and determines any shortfalls based on actual stock levels and due-ins (Gaudette et al, 2002: 5-7). Similar to EXPRESS, the Reparability Forecast Model uses probabilities and averages to determine what parts are needed. This is done out of necessity. Material Requirements Planning (MRP) systems are best suited for manufacturing environments where the Bill of Materials (BOM) provides a definitive list of what parts will be needed. Since the

Reparability Forecast Model tries to predict repair parts needed, there will almost certainly be differences between what it projects is needed and what is actually needed. The authors accept this error in the system because the Law of Large Numbers works in the favor of the Reparability Forecast Model (Gaudette et al, 2002: 7). Due to the sheer volume of work at the depots, using probabilities and averages is fairly accurate over time. However, there is still variability in the population, which is why a feedback loop is necessary.

Figure 1 shows that no direct feedback loop exists for the Reparability Forecast Model. "Materiel managers can generate special requisitions and expedite existing requisitions to meet consumable demands for repairs" (Gaudette et al, 2002: 8). This means that shortages are identified to the individuals that control the available quantities, so the shortages do not have the opportunity to cause delays. However, this information is not directly fed back to the information systems that produce the forecasts, which is depicted in Figure 1. It is possible to add a feedback loop to the process. The Reparability Forecast Model only identifies parts shortages; it does not order any parts to compensate for the projected shortages. Item managers, on the other hand, can and do place special orders if they deem it necessary to compensate for the projected shortages. If the item managers were provided with a list of parts that were currently short or that have been short over a period of time, just as this thesis suggests, it could serve as a feedback loop. In other words, if item managers were able to identify how many times and for how long their items caused work stoppages despite the Reparability Forecast Model's predictions and their special orders, item managers would be able to consider that in future orders for those parts.

There has been some recognition of the Air Force's need for a feedback loop. Kaczmarek et al argue that the Air Force needs to conduct customer-demand-oriented logistics planning. They lay out a five step methodology for demand planning. The fifth step is a feedback loop. The authors explain that a feedback loop "is key to any process for the purposes of monitoring progress and making process improvements. Additionally, feedback highlights the essential nature of demand planning as a continuously iterative process of planning, execution, assessment, and improvement in forecasting and meeting demand" (Kaczmarek et al, 2002: 20). The authors implemented their method for the F101 engine at the Oklahoma City Air Logistics Complex. The process advocated in the article produced reduced flow days, decreased response times, and had no production stoppages when given 30 days' notice of a requirement (Kaczmarek et al, 2002: 20). This shows that when provided a feedback loop, significant operational improvements can be made.

Kaczmarek et al also noted two challenges to implementation: Information Technology and Change Management. These challenges provide a warning for the progression of this research. According to the authors, extensive manual work was needed to get the information systems to do what was required of them. Finding a simple way to get the data needed from the information systems is critical to making the feedback loop useful for "rapid decision making capability" (Kaczmarek et al, 2002: 20). Also, formal training was recommended for what information to put in the systems and why it is important (Kaczmarek et al, 2002: 20).

2.5   Measurement Theory

Assuming it is possible to develop a list of parts that cause work stoppages, the next task is to prioritize that list. There are many ways to prioritize a list, and the correctness of the prioritization method is relative to what one is trying to measure. Measurement theory is defined in *Introduction to Measurement Theory* as "a branch of applied statistics that attempts to describe, categorize, and evaluate the quality of measurements, improve the usefulness, accuracy, and meaningfulness of measurements, and propose methods for developing new and better measurement instruments" (Allen and Yen, 1979: 2). One part of this thesis attempts to develop a process that allows for the collection of data that can be measured. Without the data, measurement theory is useless. Dr. David Hand touches on this in his book, *Measurement Theory and Practice: the World through Quantification*, by stating that "measurement is the activity which produces the raw material which statistical methods analyze" (Hand, 2004: 19). This thesis aims to provide the raw material necessary for statistical analysis, which may guide managers' decisions by improving their understanding of what is occurring. This task must be done carefully and methodically because measurements can also be misleading and lessen a manager's understanding of what is occurring. Dr. Hand explains this dilemma. "The measurement process extracts just one aspect of the object it is measuring and assigns a number to that aspect. But things in the real world are not described by a single aspect" (Hand, 2004: 12). This is a major limitation of any measurement (or metric). If not selected carefully, a measurement may actually do harm. In addition to selecting a measurement carefully, one must explain and understand the *purpose* of a measurement.

According to Dr. Hand, there are two measurement approaches: representational and pragmatic. "The representational aspect refers to the extent to which the numbers are chosen so that the relationships between them reflect the relationships between the objects being studied, in terms of the attribute in question" (Hand, 2004: 25). For example, the number of times various parts cause work stoppages could be compared to determine which part has the biggest negative impact. "In pragmatic measurement models the measurement procedure entirely *defines* the variable being measured" (Hand, 2004: 52). For example, I develop a way to measure impact of AWP delays on the depot repair process.

The method for developing a measure is dependent upon numerous factors, which include the objective of the measure and whether the measure must be direct or indirect (Hand, 2004: 84). Therefore, the first step is to define the objective of the measure. In this case, the objective is to develop a measurement of AWP impact which can be used to prioritize a list of piece parts causing AWP delays. Next, it must be determined if this can be measured directly or indirectly. There are many attributes that can be directly measured with regard to AWP impact, such as the amount of AWP time a part caused, the number of times it caused an end item to be AWP (frequency), the customer priority of the end item affected, the quantity needed, etc. However, it would be difficult to argue that only one of these direct measures is the best measurement by which to prioritize the list of piece parts. According to Hand, "in many situations, however, direct measurement of the attribute in question is not possible, and indirect strategies, in which its value is deduced from its relationship to other attributes, which can be directly measured, must be

used" (2004: 87). As a result, several direct measures will be combined to develop an indirect measure of AWP impact.

Since AWP impact is defined by how it is measured, a pragmatic approach is appropriate (Hand, 2004: 52). More specifically, the clinimetric approach appears best suited for the problem in this research (Hand, 2004: 15; Fayers and Hand, 2002: 240-241). Clinimetric methods are defined by Fayers and Hand as attempting "to summarize multiple attributes with a single index" (2002: 241). That is precisely what this research attempts to do. Much of the literature regarding measurement theory, particularly with regard to clinimetrics, is based on work in the behavioral sciences and medicine, but it can be easily adapted and applied to other fields as well (Hand, 2004; Fayers and Hand, 2002; Allen and Yen, 1979; Wright and Feinstein, 1992).

Fayers and Hand explain that the creators of such a measurement should choose the variables to be included and they should choose the "relative importance" of the variables (2002: 241). This should all be based on the objective of the measurement (2002: 241). In addition, they argue that this seemingly arbitrary selection method is not a weakness of the method because it forces the "constructors of a scale to decide exactly what it is they want their index to measure, and to make this public" (2002: 241). Wright and Feinstein are even more explicit about how such indexes should be developed. They explain that the clinimetric method for developing multiple-item indexes is generally done in three stages. "The first step considers a pool of candidate variables; the second step chooses the final items retained for the index; and the third step determines the relative emphasis, or 'weight', given to the retained items" (Wright and Feinstein, 1992: 1205). They recommend several methods for completing each step, such as using

individual judgment or a panel of experts (1992: 1205-1206). Section 3.2 explains how

the three-stage approach was applied to this research.

III. Methodology

3.1 Overview

This chapter will describe the methodology used for this study. It describes the AWP Impact Index development, validation, and testing. Then, it describes the gap analysis, which determined the differences between the current state and the desired end state. This analysis identified the information gaps that currently prevent the depots from tracking AWP delays by piece part.

3.2 AWP Impact Index Development

In keeping with the three-stage approach outlined in section 2.5, I selected the pool of candidate variables based on knowledge and intuition gained during the gap analysis. As the value of the candidate variable increases, so does a parts' priority on the parts list. For example, I included AWP time in such a way that as the amount of AWP time caused by a piece part increases, so does its priority on the parts list relative to the other parts. Next, the 76th Commodities Maintenance Group Deputy Commander selected subject matter experts to serve as the expert panel. The 76th CMXG Deputy Commander selected the panel members based on their knowledge and experience regarding AWP delays. The panel members included the 76th CMXG Deputy Commander, a 76th CMXG Senior Management Analyst, and a 76th CMXG Management Analyst. The panel of experts selected the final variables, defined the measurement methods, and determined the relative importance of each variable. The researcher assigned weights to each variable based on the relative importance assigned by the expert panel. As the importance decreased, so did the weights. However, depot

personnel must determine what weights are appropriate prior to use. The weights should be adjusted until depot personnel deem the resulting prioritizations correct.

3.3   AWP Impact Index Significance Test

The final variables selected were readily available direct measurements. The parts list could be prioritized based on these measurements individually, but that would ignore the other variables. In other words, the list could be prioritized by AWP time, but that would ignore the customer priority and vice versa. Therefore, it must be shown that the AWP Impact Index produces a significantly different prioritization than the individual variables. This requires the use of rank correlation methods. I used the two-tailed hypothesis test recommended for Spearman's Rank Correlation Coefficient method to test if the differences among rankings based on the AWP Impact Index and the individual variables were statistically significant. Three sources were consulted for this method. The terminology and variables from McClave et al is used in this research, but the application of the method is consistent with all three sources (Kendall and Gibbons, 1990; McClave et al, 2011; Kutner et al, 2005).

Spearman's Rank Correlation Coefficient uses various sums of squares between ranks in order to estimate the linear correlation coefficient between two sets of rankings. The correlation coefficient can range between -1 (perfect negative correlation) and +1 (perfect positive correlation). The closer the coefficient is to -1 or +1, the more correlated two rankings are. The closer the coefficient is to zero, the less correlated two rankings are (McClave et al, 2011: 14—37-40). Finally, there are two conditions that must be met in order to properly test the significance of the Spearman's rank correlation coefficients. First, the sample must be randomly selected. Second, the probability

distributions of the two variables selected must be continuous (McClave et al, 2011: 14—42).

In this case, piece parts must be randomly selected from the data. There is no specific discussion of recommended sample sizes in the literature, but the sample sizes of the examples provided in the literature ranged from 10 to 20 (McClave et al, 2011: 14—37-44; Kutner et al, 2005: 87-89; Kendall and Gibbons, 1990: 69-71). Therefore, 20 piece parts were randomly selected to ensure the sample size was large enough. The data provided by the 76th Commodities Maintenance Group included 615 piece parts. The researcher listed the parts in ascending order in Microsoft Excel by the National Stock Number (NSN), which is an alphanumeric assigned to each piece part in the Department of Defense. The RAND() function in Excel assigned a random number between 0 and 1 to each piece part. Next, I sorted by the random number in ascending order and selected the first 20 piece parts to use as the random sample from the population.

The next step was to determine the correlation coefficient for each pairing of the variables. There are two equations that can be used to calculate the correlation coefficient. One is the "full" equation; the other is a shortcut equation that is appropriate when there are no ties in.

$$r_s = \frac{SS_{uv}}{\sqrt{SS_{uu}SS_{vv}}}$$

Where

r_s = sample rank correlation coefficient

ρ = population rank correlation coefficient

$$SS_{uv} = \sum_{i=1}^{20}(u_i - \bar{u})(v_i - \bar{v})$$

$$SS_{uu} = \sum_{i=1}^{20}(u_i - \bar{u})^2$$

$$SS_{vv} = \sum_{i=1}^{20}(v_i - \bar{v})^2$$

u_i = Rank of ith observation in sample 1

v_i = Rank of ith observation in sample 2

The method requires assigning the average of the applicable ranks to any piece parts that have tied measurements. For example, if the quantity for three piece parts is 5, and they occupy the rankings 5, 6, and 7, each part is assigned the rank of 6. Then, the researcher used a two-tailed hypothesis test to determine each coefficient's statistical significance ($\alpha = 0.005$). With a two-tailed hypothesis test and an alpha of 0.005, the critical value is 0.612 (Zar, 1972: 578-80). The test is outlined below:

H_0: $\rho = 0$

H_a: $\rho \neq 0$

Test Statistic: r_s, the sample rank correlation coefficient

Rejection Region: $|r_s| > r_{s,0.005/2} = 0.612$

This hypothesis test involves a pair wise comparison of each possible combination of the methods used to rank the piece parts. In section 4.2, the expert panel selected five variables for calculating the AWP Impact Index. Therefore, fifteen {C(6,2)} pair wise comparisons must be made. The piece part rankings provided by each variable and the AWP Impact Index must be compared with each other to determine if the AWP Impact Index produces rankings that are significantly different. In addition, the comparisons identify if there are any variables' piece part rankings that are **not** significantly different. As a result of making fifteen simultaneous comparisons, when the null hypothesis is rejected, the confidence of the rejection must be adjusted to reflect the number of

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rejections. The Bonferroni method shows that the statement of family confidence for the rejections made is $1 - g\alpha$, where g is the number of rejections (Kutner et al, 2005: 155-157). For example, Table 1 shows that 7 correlation coefficients were significantly correlated. The level of confidence of this statement is $1 - (7)(0.005)$ or 0.965.

3.4   AWP Impact Index Practical Comparisons

In addition to the statistical rank correlation method used above, the researcher conducted three practical comparisons. The Spearman's rank correlation coefficient is useful for determining if the differences in rankings are statistically significant, when comparing the same randomly selected parts. However, it does not allow for a comparison of how all piece parts are ranked across all variables. I could not find a statistical test for such a comparison, so I created three practical comparisons. In these practical comparisons, I ranked the entire population of piece parts by the AWP Impact Index, which is developed in section 4.2, and each variable individually.

The first comparison method used the same 20 piece parts as the Spearman's method. The researcher compared the rankings of those 20 piece parts across all variables to the rankings assigned by the AWP Impact Index, since it is the measurement under consideration. I then calculated the difference between the rank assigned by AWP Impact Index and the individual variables. This allowed for a positive or negative result. Intuitively, if the AWP Impact Index ranked the parts properly, the absolute value of the difference should be larger as the relative importance of the variable decreases. This aids in determining if the AWP Impact Index applied the relative importance of each variable properly. This also allows for a comparison of how each variable ranked the same part in relation to the entire population of data.

The second comparison identified commonalities, instead of differences. Again, the researcher compared the AWP Impact Index rankings and the rankings by the five variables using the entire population. This involved comparing the top 20 piece parts for each variable to the top 20 piece parts as ranked by the AWP Impact Index. I searched for the top 20 piece parts identified by the AWP Impact Index in each of the other variables' top 20 piece parts. I counted and highlighted any instance of a piece part commonality in the top 20 by each variable.

The logic behind this method is that the depot leadership will mostly be concerned with only the most troublesome parts, but they will also look at more than just the highest ranked piece part. Therefore, it's useful to understand how much commonality there is among the top rankings. This is particularly useful as priorities change. For example, if warfighter priority becomes more important than cost, then depot leadership should want to know if the rankings by Spares Priority Release Sequence priority are the same as the ranking by cost ratio. Otherwise, switching prioritization methods may not give different priorities.

The third comparison identified agreement by quintile. The author ranked each of the 607 piece parts according to the AWP Impact Index and each variable. The rankings were then divided into 5 quintiles. I compared the rankings by each variable to the ranking by the AWP Impact Index. I calculated the number of times the same piece part was in the same quintile for each respective comparison. This showed the amount of agreement by quintile for each comparison. This method provided a better understanding of the agreement across the entire population of data as opposed to 20 randomly selected piece parts or the top 20 piece parts.

However, it's important to remember that these three comparisons only highlight the differences or commonalities among the rankings. They do not identify which measurement is better or best. The accuracy of the rankings assigned to each part can only be determined by the users of the measurements, since there is no universal or completely objective standard for measuring AWP impact.

3.5   Gap Analysis

The gap analysis identified the differences between the desired end state and the current state of the information recorded throughout the repair process. Specifically, the gap analysis identified where work stoppages (delays) can occur in the repair process due to parts unavailability and what information is recorded about those delays. The researcher used this information to describe the current state. Next, I defined the desired end state. Finally, I compared the two states to determine what differences existed.

Prior to conducting the gap analysis, an understanding had to be gained of the basic repair process that end items follow once they are inducted into the 76th Commodities Maintenance Group (CMXG). The leadership of the 76th CMXG identified managers and supervisors within the 76th CMXG as subject matter experts (SMEs). These SMEs explained the basic repair process. The SMEs created a flow chart of the process (depicted in Figure 2).

Induction → Kitting* → Disassembly → Repair & Assembly ⇄ Test → Sell
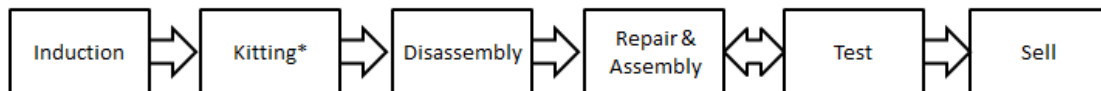
Figure 2. Flow Chart of Repair Process

With the basic flow chart established, it was necessary to determine where AWP delays could occur. The researcher created a tentative flow chart with delay locations through emails and phone calls with various SMEs within the 552nd Commodities Maintenance Squadron (CMMXS), which is a unit in the 76th Commodities Maintenance Group. However, I modified the flow chart and delay locations after I conducted on-site discussions with schedulers. The researcher held discussions with schedulers from the fuels accessories shop, governors and accessories shop, and constant speed drives (CSD) shop. The subject matter experts selected these shops because their processes presented the widest range of variability to the basic process in Figure 2. In other words, studying the processes within these three shops gave the best understanding of the rest of the shops in the 76th Commodities Maintenance Group. The researcher asked schedulers to describe any process variations that could occur. In some cases, we brought work center supervisors into the discussion to clear up any uncertain information. Throughout all these discussions, I specifically asked for statements of fact only and strictly avoided individual opinions and conjecture to ensure I gained an unbiased understanding of the process. Then, I verified the locations of possible AWP delays. This step was critical to developing the desired end state and to focus the information mapping to only the pertinent steps in the repair process.

Next, the author examined the same three shops in detail to determine the current state. I examined each step in the repair process depicted in Figure 2, except Test and Sell. I did not examine the Test and Sell steps because no AWP delays can occur in them. Subject matter experts, such as schedulers, work leaders, and mechanics explained what occurred at each step of the repair process. They also explained any possible

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deviations from the basic repair process in Figure 2. This ensured that any recommendations provided in Chapter 5 would account for the variation in process execution. After I visited all three shops, I created process flow charts for each shop and then a consolidated flow chart depicting what information is recorded at each step and the information system in which it is recorded.

The same subject matter experts verified the accuracy of the flow charts. In addition, the applicable information systems offices of primary responsibility (OPRs) at Tinker AFB verified the accuracy of the flow charts. The system OPRs validated that the information was actually recorded where the subject matter experts stated it was recorded. The researcher discussed the accuracy of the data with the subject matter experts and system OPRs as well, so the validity and reliability of the information recorded could be ascertained.

Then, I defined the desired end state. It must be reiterated that the objective of this gap analysis was not to change the repair process. The objective of this analysis was to determine what information should be recorded and in what information system(s) it should be recorded, so a list of piece parts causing delays could be created. The variables identified by the panel of experts discussed in section 3.2 drove what information should be recorded about the delays. The desired end state had to include all the information necessary to use the AWP Impact Index.

Finally, the researcher compared the two states to identify the gaps that existed between them. With the gaps identified, the final step was to develop a process to close the gaps. I developed two possible solutions. The same subject matter experts and

information systems offices of primary responsibility validated the solutions for

feasibility, validity, and cost (time and money).

IV.   Analysis and Results

4.1   Overview

This chapter provides a detailed explanation of the development of the AWP

Impact Index, the significance of the index prioritizations, the comparisons with the

individual variables, and the gap analysis results. The expert panel determined that the

AWP Impact Index should include AWP time, quantity, frequency, warfighter priority,

and cost ratio. The testing results show that the AWP Impact Index produced priorities

significantly different from the individual variables, except AWP time. In addition, the

gap analysis identified where AWP delays can occur, the current state, and desired end

state of information being recorded regarding AWP delays. The results show that the gap

between the information currently being recorded about AWP delays and the desired end

state is not that wide. In the governors and accessories shop, all information needed to

track AWP delays by piece part is already being recorded. In the fuels accessories and

CSD shops, the kitting step is the only step that needs more information recorded to

achieve the desired end state.

4.2   AWP Impact Index Development

The researcher developed the AWP Impact Index in three stages. First, I

compiled a list of variables based on knowledge and intuition gained during the gap

analysis. Second, the 76th Commodities Maintenance Group assembled an expert panel

to select the final variables and how to measure each of them. Third, the panel of experts

determined the relative importance of each variable. Finally, the AWP Impact Index was

tested to determine if it produced results that were significantly different than the

individual variables and to see if the variables were significantly different from each other.

4.2.1 Initial Variable Selection

Any variable selected that indicates increased AWP impact should cause the part's index value to increase. As a result, the researcher selected the variables below for consideration by the panel of experts:

- Increased Cost Ratio (C_E/C_P)
    - End Item Cost (C_E)
    - Piece Part Cost (C_P)
- Increased Quantity Needed (Q)
- Increased AWP Time (T)
- Increased SPRS Priority (S)
- Increased Frequency (F_P)

The cost ratio is meant to represent the tradeoff between buying more end items or more piece parts to ensure the customers' needs are met. For example, it is better to buy more of a piece part that costs ten cents than to buy more of an end item that costs $10,000. In addition, it would be foolish to have a ten cent part delay the repair of a $10,000 end item. Therefore, as the cost ratio increases, so should the piece part's priority. The quantity of a piece part needed should also drive up its priority because as the quantity increases, so does the severity and impact of the shortage. The AWP time is an important factor to include in the index because as the AWP time increases, so does the severity and impact of the shortage. The frequency also contributes to the severity and impact of the shortage because frequent, short delays can have the same impact as one long delay.

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Finally, the Air Force assigns a Spares Priority Release Sequence (SPRS) priority to very high priority end items. EXPRESS creates a prioritized list of end items that need repaired based on the factors discussed in section 2.2, but the Spares Priority Release Sequence "reorders item priorities based on specific field requisitions. The priority sequence assigns a priority to each item needed in the total worldwide requirement" (Air Force Materiel Command, 2006: 4). The Spares Priority Release Sequence priority values range from 0 to 84. As the value increases, so does the priority of the end item (Air Force Materiel Command, 2006: 25-26). Therefore, the Spares Priority Release Sequence priority is a direct measure of customer priorities and as it increases, so should the priority of the piece part.

4.2.2   Final Variable Selection by Expert Panel

The researcher presented the variables listed in section 4.2.1 to the panel of experts to assess if the variables were appropriate to be included in the index and if any variables needed to be added. The panel determined that all five variables presented should be included in the AWP Impact Index and that no other variables should be added. The panel also defined how each variable should be measured. They determined that the cost ratio should be measured with the sell price of the end item and the purchase price of the piece part. The panel decided that the quantity variable should count the piece parts shortage quantity when attributed to an AWP delay. They also determined that AWP time should be measured from the start of any delay to the repair process due to parts unavailability (i.e.-when an R06 delay code is entered in the Time, Attendance, and Accountability system) and end when the last part needed to recommence repairs arrived. In addition, the panel determined that the AWP time should only be recorded against the

last piece part to arrive. The panel decided that the frequency should count the number of times a piece part caused a delay (i.e. – an end item gets delayed three times by three different parts; one delay would be recorded against each part).

4.2.3 Relative Importance of Variables

The panel also determined the relative importance of each variable, which are listed below in descending order or importance:

1. Increased Frequency (F_P)

2. Increased AWP Time (T)

3. Increased Quantity Needed (Q)

4. Increased Cost Ratio (C_E/C_P)

5. Increased SPRS Priority (S)

4.2.4 Data Collection for Variables

The optimal method to compare the various prioritizations created by the individual, direct measurements would be to use actual data. However, since the primary focus of this research is to identify if such data can even be obtained, actual data was not available for all variables. The 76th Commodities Maintenance Group provided data on the current end items in formal AWP status. The data is current as of January 27, 2013 and included the end item National Stock Numbers, piece part National Stock Numbers, formal AWP time (days), quantity of piece parts needed, and the frequency of AWP delays. The 76th Commodities Maintenance Group also provided the end item sell prices, which they pulled on January 31, 2013. In addition, Air Force Materiel Command provided the piece part purchase prices and the Spares Priority Release Sequence priorities of the end items from EXPRESS, which is accurate as of February 4, 2013.

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Actual AWP time data was used, but it was not measured in the same manner as it is described in section 4.2.2. The AWP time data only measured the number of days in formal AWP status. However, this is an understatement of the total AWP time. The AWP time data used ranged from 18 days to 999 days. This prevents the evaluation of the impact of many small delays. In addition, the system used by the Oklahoma City Air Logistics Complex to track formal AWP days stops counting time after 999 days. This prevents the evaluation of the impact of delays beyond 999 days. As a result, it is unknown what impact, if any, the extreme values for AWP time will have on the prioritization of parts. However, this weakness is somewhat mitigated by the fact that the AWP time data used contains a wide range of values.

In addition, the research could not always attribute the AWP delay to just one part since the data was based on current end items in formal AWP status. Some end items had multiple parts backordered against it. This made it impossible to apply the measurement method prescribed in section 4.2.2. To account for this, I treated each backordered part as a separate delay, even if it was one of many parts causing the delay for that particular end item. Since this data is not being used to make operational decisions, there is no harm in doing this. Finally, an inherent limitation to using the Spares Priority Release Sequence priority is that it can change daily. As a result, the Spares Priority Release Sequence priority assigned to each end item was based on data pulled from EXPRESS on February 4, 2013.

Pricing data could not be located for eight piece parts. The researcher identified the 20 randomly selected piece parts prior to this realization, but all of the 20 parts selected had the necessary data. Therefore, the missing data had no effect on the analysis

using the Spearman's significance test. However, this could have affected the outcome

for the practical comparisons since I ranked the entire data population. While none of the

eight parts were one of the 20 randomly selected parts, the eight piece parts missing

pricing data had to be excluded. The eight parts should not have a major effect on the

results because the applicable values were low for all eight parts: end item sell prices

($1,598 - $152,522), Spares Priority Release Sequence priorities (none assigned), piece

part quantities (1 – 8), and frequencies (1 – 8).   The AWP time on the eight parts ranged

from 40 days to 3,813 days. However, even the part with 3,813 AWP days would have

been ranked 42 by AWP time across the entire population. While the AWP time is

somewhat high for some of the excluded parts, the effect on the results and conclusions

should be minimal due to their low values in the other variables.

4.2.5   AWP Impact Index

With the final variables selected and the necessary data collected, the next step

was to combine the variables in such a way as to get the proper effect from them. The

desired effects of each were described in section 4.2.1 and validated/clarified in sections

4.2.2 and 4.2.3. The researcher developed the following equation for the AWP Impact

Index based on those desired effects:

$$I_P = (w_F F_P) + \left[w_T \left(\frac{\sum_{i=1}^{F_P} T_i}{F_P} \right) \right] + \left[w_Q \left(\frac{\sum_{i=1}^{F_P} Q_i}{F_P} \right) \right] + \left[w_C \left(\frac{\sum_{i=1}^{F_P} \left(\frac{C_E}{C_P} \right)_i}{F_P} \right) \right] + \left[w_S \left(\frac{\sum_{i=1}^{F_P} S_i}{F_P} \right) \right]$$

Where

I_P = AWP Impact Index by Piece Part

T = AWP Time, length of delay (days)

Q = Quantity, shortage per delay (each)

S = SPRS Priority, end item priority per delay

C_E = Sell Price of End Item (dollars)

C_P = Purchase Price of Piece Part (dollars)

F_P = Number of AWP delays caused by Piece Part

P = Piece Part (1, 2, 3…n)

n = Number of piece parts

w_F = Weight assigned to Frequency

w_T = Weight assigned to AWP Time

w_Q = Weight assigned to Quantity

w_C = Weight assigned to Cost Ratio

w_S = Weight assigned to SPRS Priority

The AWP Impact Index (I_P) provides a value that has no meaningful unit of measure. It is only useful when comparing the effects of different piece parts and to compare different AWP impact indices. Each of the variables has a different scale, so the raw data was normalized. To normalize the data, I divided each data point by the maximum value for that variable. I also normalized the weights by dividing each raw weight by the sum of the weights.

In accordance with the recommendations in sections 4.2.2 and 4.2.3, as each of the variables increase, so does the index value of the piece part. Summing the AWP time, quantity, cost ratio, and Spares Priority Release Sequence priority for each delay double counts the frequency since there is a separate variable for frequency. Therefore, the researcher used the average of each variable, except frequency. The researcher did

not use the average frequency because the average frequency over one time period is one. By using averages, the variables with consistently high values receive a higher priority than variables with a few instances of high values. Normalizing the data and applying weights to each variable allows users to adjust the equation as the importance of variables change.

4.2.6 Analysis of AWP Impact Index and Variables

The following four tests compare the AWP Impact Index rankings to the rankings by each variable. These tests determine if the rankings are different. They do not identify which prioritization method is best. To determine the rankings by each variable, the researcher summed the values of each variable by piece part, and then ranked them in descending order by the variable value. This is based on the assumption that depot personnel will choose between using the index rankings or the rankings of one or more of the variables. Depot personnel would compare the variables separately, so double counting the frequency is not a concern as it was for the AWP Impact Index.

For the Spearman's test to be valid, two conditions must be met. The sample must be randomly selected and the probability distributions of the two variables being compared must be continuous. The researcher selected a random sample as described in section 3.3. The AWP Impact Index and the variables are effectively continuous because the raw data is normalized. Table 1 displays the results of the fifteen significance tests. All cells with a shaded background showed a statistically significant correlation. The researcher coded the AWP Impact Index with the letter I and each variable with a number (1, 2, 3, 4, 5) that also corresponds to its relative importance.

Table 1. Spearman's Rank Correlation Test Results

Spearman's Rank Correlation Coefficients (r_s), n=20, α = 0.005, $r_{s,\alpha/2}$ = 0.612						
Variables	AWP Impact Index (I)	Frequency (1)	AWP Time (2)	Quantity (3)	Cost Ratio (4)	SPRS Priority (5)
AWP Impact Index (I)	-	0.32	0.65	0.49	0.50	0.32
Frequency (1)	-	-	0.65	0.90	0.16	1.00
AWP Time (2)	-	-	-	0.64	0.01	0.65
Quantity (3)	-	-	-	-	0.20	0.90
Cost Ratio (4)	-	-	-	-	-	0.16
SPRS Priority (5)	-	-	-	-	-	-

Some of the correlations are not surprising. For example, the researcher expected that frequency and AWP time would be correlated since AWP time is the sum of the AWP time for each delay. Also, quantity and frequency were expected to be correlated because 50% of the sample had a quantity of one and 55% of the sample had a frequency of one. For the same reason, quantity and AWP time were highly correlated. Spares Priority Release Sequence priority was highly correlated with frequency, AWP time, and quantity because only one part in the sample caused a delay on an end item that had a Spares Priority Release Sequence priority assigned to it. As a result, the Spares Priority Release Sequence priority and frequency were perfectly correlated. Finally, AWP Impact Index and AWP time were highly correlated (r_s = 0.65).

The practical comparison to determine differences produced results similar to the Spearman method. The coding scheme is the same as used in Table 1. Table 2 shows how the AWP Impact Index and each variable ranked the same random 20 piece parts within the entire population of data (n = 607). Table 3 shows the differences between the AWP Impact Index rankings and the rankings by each variable. Table 4 shows the

absolute values of the differences displayed in Table 3 and the sums of the absolute

differences.

Table 2. Rankings across the Data Population

Piece Part NSN	AWP Impact Index (I)	Frequency (1)	AWP Time (2)	Quantity (3)	Cost Ratio (4)	SPRS Priority (5)
5961012448488EH	5	6.5	4	10.5	270	5
1560015823928FL	11	60	50	78	53	101
1680PH091417F	35	93.5	114	106	447	145
5342PH099938F	86	491.5	145.5	497.5	232	503.5
1650001382564	157	247.5	372	81	75.5	280.5
5961015880476	223	491.5	228.5	497.5	458	503.5
5365PH100973F	271	247.5	276	261	177	280.5
1560015894865	276	247.5	294	261	518	280.5
4730015470079	344	491.5	330.5	181.5	309	503.5
5360011651571SX	345	324.5	326	335.5	509	352.5
1560013523948FG	408	247.5	353	261	355	280.5
1680010136374SX	424	491.5	350.5	497.5	345	503.5
1560010704977FG	463	324.5	426.5	335.5	60	352.5
1560015516445	467	491.5	462	497.5	344	503.5
5330012196008SX	476	491.5	493	497.5	229	503.5
1560015655767	523	491.5	532.5	497.5	272	503.5
5962014962987EK	524	491.5	538.5	497.5	243	503.5
4810004637646HS	526	491.5	549.5	497.5	134	503.5
1660NCZ084485BQ	543	491.5	545	497.5	577	503.5
5977003527037EH	591	491.5	589	497.5	406	503.5

Table 3. Differences between Rankings

Piece Part NSN	(I,1)	(I,2)	(I,3)	(I,4)	(I,5)
5961012448488EH	-1.5	1	-5.5	-265	0
1560015823928FL	-49	-39	-67	-42	-90
1680PH091417F	-58.5	-79	-71	-412	-110
5342PH099938F	-405.5	-59.5	-411.5	-146	-417.5
1650001382564	-90.5	-215	76	81.5	-123.5
5961015880476	-268.5	-5.5	-274.5	-235	-280.5
5365PH100973F	23.5	-5	10	94	-9.5
1560015894865	28.5	-18	15	-242	-4.5
4730015470079	-147.5	13.5	162.5	35	-159.5
5360011651571SX	20.5	19	9.5	-164	-7.5
1560013523948FG	160.5	55	147	53	127.5
1680010136374SX	-67.5	73.5	-73.5	79	-79.5
1560010704977FG	138.5	36.5	127.5	403	110.5
1560015516445	-24.5	5	-30.5	123	-36.5
5330012196008SX	-15.5	-17	-21.5	247	-27.5
1560015655767	31.5	-9.5	25.5	251	19.5
5962014962987EK	32.5	-14.5	26.5	281	20.5
4810004637646HS	34.5	-23.5	28.5	392	22.5
1660NCZ084485BQ	51.5	-2	45.5	-34	39.5
5977003527037EH	99.5	2	93.5	185	87.5

Table 4. Absolute Values of Differences

Piece Part NSN	(I,1)	(I,2)	(I,3)	(I,4)	(I,5)
5961012448488EH	1.5	1	5.5	265	0
1560015823928FL	49	39	67	42	90
1680PH091417F	58.5	79	71	412	110
5342PH099938F	405.5	59.5	411.5	146	417.5
1650001382564	90.5	215	76	81.5	123.5
5961015880476	268.5	5.5	274.5	235	280.5
5365PH100973F	23.5	5	10	94	9.5
1560015894865	28.5	18	15	242	4.5
4730015470079	147.5	13.5	162.5	35	159.5
5360011651571SX	20.5	19	9.5	164	7.5
1560013523948FG	160.5	55	147	53	127.5
1680010136374SX	67.5	73.5	73.5	79	79.5
1560010704977FG	138.5	36.5	127.5	403	110.5
1560015516445	24.5	5	30.5	123	36.5
5330012196008SX	15.5	17	21.5	247	27.5
1560015655767	31.5	9.5	25.5	251	19.5
5962014962987EK	32.5	14.5	26.5	281	20.5
4810004637646HS	34.5	23.5	28.5	392	22.5
1660NCZ084485BQ	51.5	2	45.5	34	39.5
5977003527037EH	99.5	2	93.5	185	87.5
SUM	1749.5	693	1722	3764.5	1773.5

Table 4 shows that the sum of absolute differences is smallest between the AWP Impact Index and the AWP time rankings, which indicates AWP time could have too much influence on the AWP Impact Index. This supports the results found with Spearman's method in Table 1. However, adjusting the weights could mitigate this effect if the users deem it undesirable.

Tables 5 and 6 show the results of the practical comparison to determine commonalities. Table 5 shows which piece parts were ranked in the top 20 by the AWP Impact Index and each variable. The second vertical column in Table 6 shows how many times a piece part from the AWP Impact Index's top 20 made it into the top 20 of the other variables' rankings. The bottom row in Table 6 shows how many times a variable ranked the same part within the top 20 as the AWP Impact Index. Finally, it shows the

population rankings of each piece part by each variable. If a variable ranked the piece

part in the top 20, the cell for that piece part is shaded. The results in Table 6 support the

findings in the previous two methods. The AWP Impact Index and AWP time the highest

number of commonalities, which suggests AWP time has an overpowering effect on the

AWP Impact Index rankings. Again, adjusting weights is a mitigation option.

Table 5. Top 20 Piece Parts by AWP Impact Index and each Variable

Rank	AWP Impact Index (I)	Frequency (1)	AWP Time (2)	Quantity (3)	Cost Ratio (4)	SPRS Priority (5)
1	6105003175643SX	6105003175643SX	6105003175643SX	6105003175643SX	4010012848086	6105003175643SX
2	5331013608012BQ	1560PH100424F	1560002133595FL	1560PH100398F	5331013608012BQ	5360003361029SX
3	4730PH095404F	1560002133595FL	6105007838732SX	5331013608012BQ	5330014353459SX	1660011244775
4	1560002133595FL	1560PH100398F	1560015823928FL	1560PH100424F	5306PH099180F	1560001827145FL
5	5961012448488EH	3040011830215JF	1660012075403	1560002133595FL	1560014586936SX	1560015823928FL
6	3010002749624UC	1680012471806RK	3110000791181	5306PH099180F	5306PH099179F	1660015266169
7	4010012848086	1560015823928FL	1660011244775	3110000791181	5330005914669	2915012078715SX
8	6150011617564HS	4810013884700TP	3110009459317	3040011830215JF	1560015436165FL	2935011938067PN
9	3040010304435AW	1660015266169	4810013884700TP	5340010836689SX	1560007662589FL	6620000865223
10	1660011244775	1660012075403	5930011799694EK	1680012471806RK	5365000646283SX	2915012037050PR
11	1560015823928FL	6105012328318NT	4730PH095404F	1560015823928FL	5310012926334SX	2915009074704SX
12	6105007838732SX	6105007838732SX	5310003307757SX	4810013884700TP	1560009411214FL	3120012455083FX
13	3040015908392	3110000791181	1560PH100424F	1660015266169	5325PH085666F	5325PH085666F
14	1560010390680AW	1650001811760	5945010441702TP	2840012370594PN	5310000799661SX	1680010036945SX
15	6105004841890HY	1660008664250	1650012108535HS	1660012075403	5340010836689SX	2915011827053JF
16	1660012075403	6150001789569VH	2915012037050PR	6105012328318NT	9905012461514FX	5330013427775SX
17	1680015954309	1650001339481HS	1560011900597FG	5306PH099179F	5330013613149FW	4810004609188SX
18	3110000791181	6680002203265UC	3040012426619HS	6105007838732SX	5340007986885HS	4810010553406SX
19	5945010441702TP	1560016032651	1650001811760	1650001811760	1560006519167FL	1660015267017
20	1560PH100424F	1660005225938	6105012328318NT	1660008664250	1560015453064	9905012461514FX

Table 6. Summary of Commonalities across Top 20

Piece Part NSN	# of Top 20 in Common with AWP Impact Index Top 20	Rankings					
		AWP Impact Index (I)	Frequency (1)	AWP Time (2)	Quantity (3)	Cost Ratio (4)	SPRS Priority (5)
6105003175643SX	4	1	1	1	1	80	1
5331013608012BQ	2	2	184	367	3	2	237.5
4730PH095404F	1	3	81	11	46	25	127
1560002133595FL	3	4	3	2	5	23	26
5961012448488EH	0	5	491.5	145	497.5	232	503.5
3010002749624UC	0	6	491.5	146	497.5	462	503.5
4010012848086	1	7	247.5	144	106	1	280.5
6150011617564HS	0	8	247.5	64	261	516	280.5
3040010304435AW	0	9	491.5	204	497.5	269	78.5
1660011244775	2	10	25	7	32.5	319	3
1560015823928FL	4	11	6.5	4	10.5	270	5
6105007838732SX	3	12	13	3	18.5	408	51
3040015908392	0	13	491.5	191	497.5	527	503.5
1560010390680AW	0	14	213	52	216.5	379	237.5
6105004841890HY	0	15	101	28	126.5	522	162
1660012075403	3	16	10	5	14.5	231	45
1680015954309	0	17	324.5	124	335.5	141	37
3110000791181	3	18	13	6	7	57	51
5945010441702TP	1	19	54.5	14	51.5	443	95.5
1560PH100424F	3	20	2	13	4	107	25
# of Top 20 in Common with AWP Impact Index Top 20			7	10	8	2	3

The third comparison used quintile agreement to show how the ranking methods compared across the population of piece parts. In Figures 3-7, the vertical axis shows how many times the AWP Impact Index and the variables ranked the same piece part in the same quintile for each comparison, and the horizontal axis indicates the quintile. The bar charts indicate a higher amount of agreement in the first and fifth quintiles. This could be the result of piece parts with extreme values (high or low) consistently driving those piece parts into the highest and lowest rankings regardless of the ranking method. The charts also show that AWP time had higher agreement regardless of quintile compared to the other four variables. This supports the findings in the previous three comparison methods.
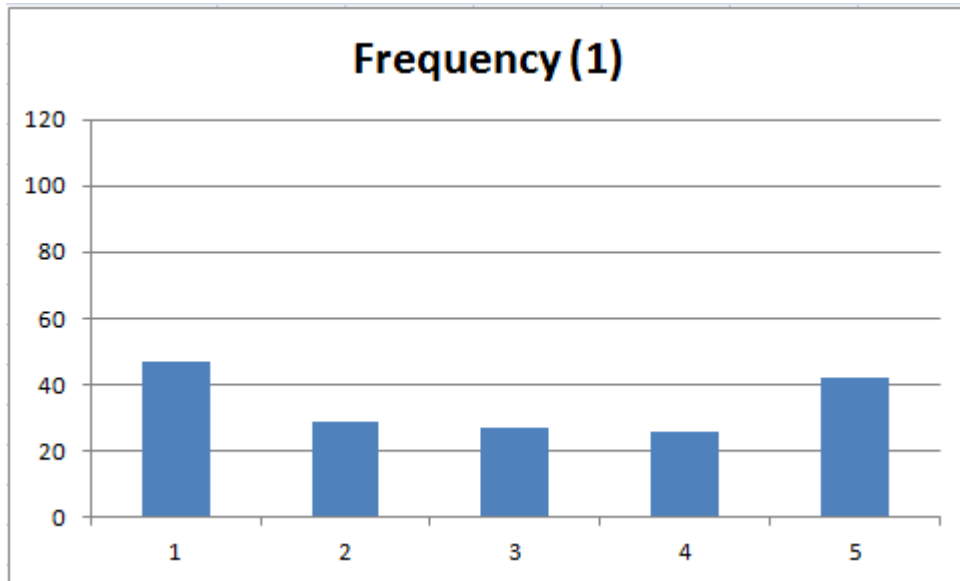
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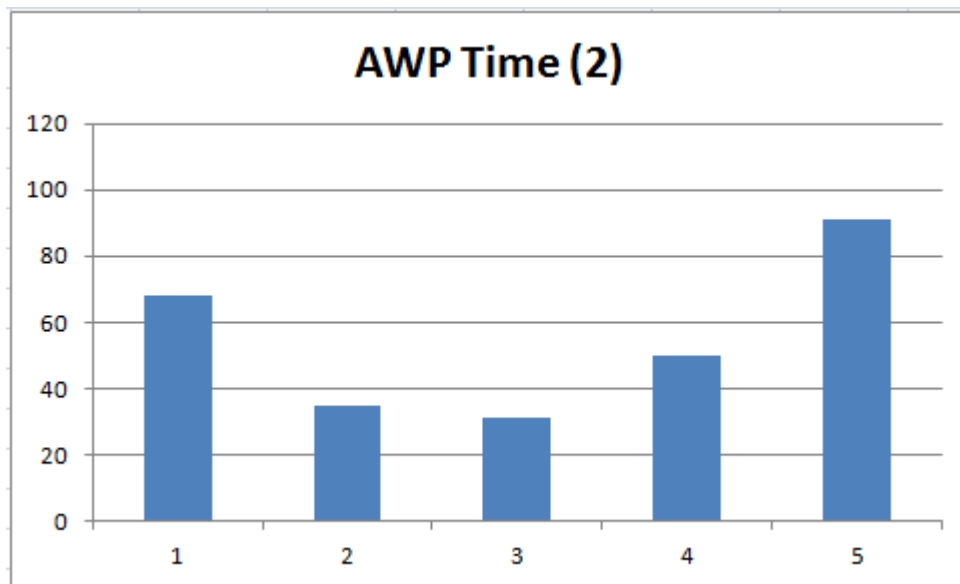Figure 3. AWP Impact Index and Frequency (1) Quintile Agreement

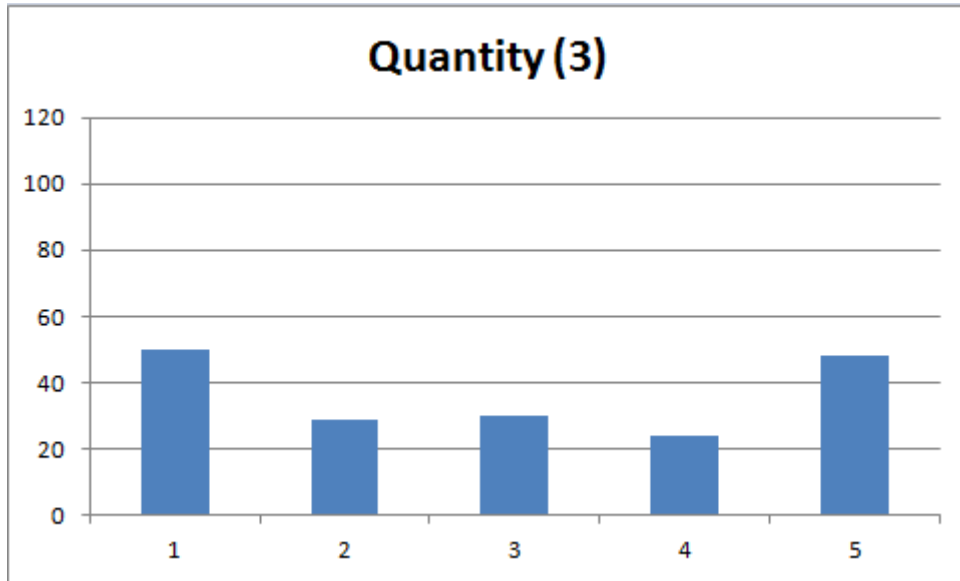Figure 4. AWP Impact Index and AWP Time (2) Quintile Agreement

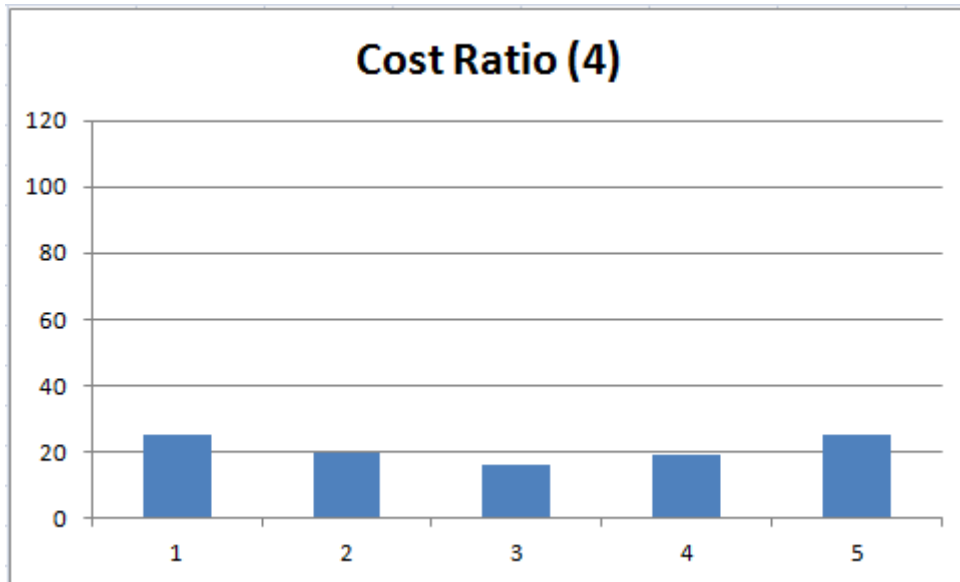Figure 5. AWP Impact Index and Quantity (3) Quintile Agreement

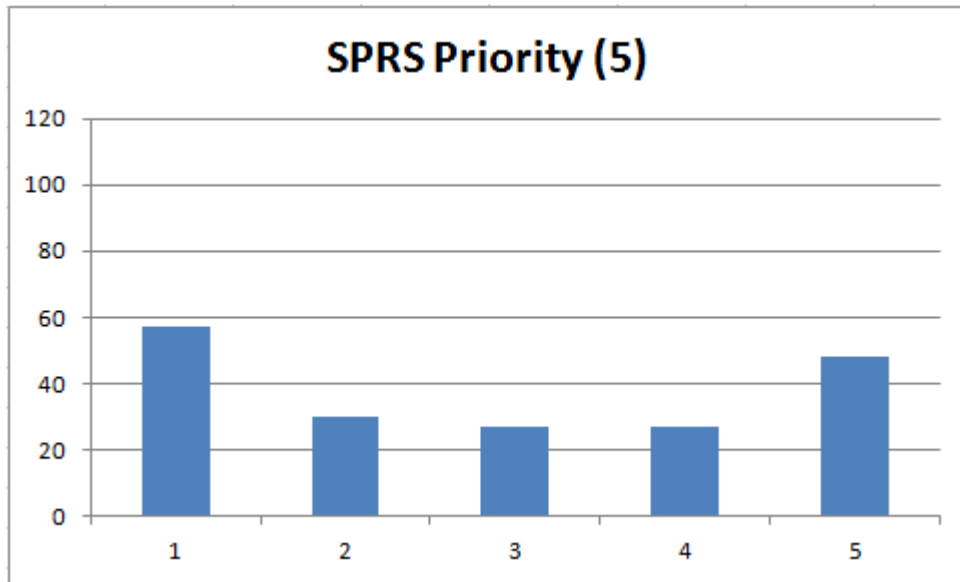Figure 6. AWP Impact Index and Cost Ratio (4) Quintile Agreement

Figure 7. AWP Impact Index and SPRS Priority (5) Quintile Agreement

Whether or not the AWP Impact Index produces a better prioritization of piece

parts than the individual variables is a determination that the 76th Commodities

Maintenance Group must make. Only they have the ability to determine if the

prioritization reflects the true nature of AWP impact. To aid in that decision, the

researcher extracted some examples from the data of the major prioritization differences.

They are displayed in Table 7. Any piece part ranked between 1 and 30 is shaded.

Table 7. AWP Impact Index Extreme Differences

Piece Part NSN	AWP Impact Index	Frequency (1)	AWP Time (2)	Quantity (3)	Cost Ratio (4)	SPRS Priority (5)
1560PH100398F	0.20	56	7216	112	374	56
4810013884700TP	0.18	36	10523	36	88	36
3040011830215JF	0.16	49	4426	49	216	49
1680012471806RK	0.16	43	5686	43	357	43
1660015266169	0.14	35	2969	35	258	350
5330014353459SX	0.11	9	1468	9	25893	9
1560014586936SX	0.10	11	1288	17	20466	11
5340010836689SX	0.10	10	563	45	4995	10
1560007662589FL	0.09	3	307	3	9988	3
1560015436165FL	0.08	7	686	7	15040	7
1560009411214FL	0.07	9	938	9	8472	9
1560015453064	0.06	2	202	2	3074	2
5360144832003SX	0.06	4	134	4	331	61
1560015518617	0.05	2	187	2	2005	2

Table 7 shows how the AWP Impact Index produces prioritizations that contradict the prioritizations of the most important variables identified by the expert panel. Most of the differences are between cost ratio rankings and all other variables' rankings. These differences appear to cause some piece parts (i.e.-the second, third, fourth, and fifth listed in Table 7) to not be ranked in the top 30 by the AWP Impact Index, despite two or more variables ranking them in the top 30. These contradictions must be considered if the AWP Impact Index is to be implemented by the depot. However, another important detail to recognize is the high amount of agreement among frequency, AWP time, and quantity. While these are not differences, subject matter experts should examine the similarities as well to determine if the parts are ranked properly. Subject matter experts in the 76th Commodities Maintenance Group should examine the examples in Table 7 to determine if such rankings are appropriate. In addition, subject matter experts can use such comparisons to determine whether or not change the weights assigned to variables.

4.3   Gap Analysis Results

Prior to the on-site data collection, the researcher collected information about the general repair process via email and phone discussions. This was done to limit the amount of on-site time required and to ensure on-site discussions were as productive and focused as possible. Narrowing the researcher's knowledge gap prior to the on-site visit was absolutely crucial to knowing what questions to ask, but more importantly, to know what terminology to use so questions would elicit accurate, factual responses. All on-site information gathering used the flow chart in Figure 2 as a basis.

4.3.1   Fuels Accessories Shop

The first shop visited was the fuels accessories shop. The scheduler first provided an overview of the repair process of the fuels accessories shop. Then, the researcher conducted a physical walk through of the process to ensure accuracy of the information received by the scheduler. A mechanic also provided details about the Disassembly and Repair & Assembly steps. In addition, the technicians who perform the Kitting step provided details about their work. The process is depicted in Figure 8. Kitting is depicted with an asterisk because not all end items go through the Kitting step.
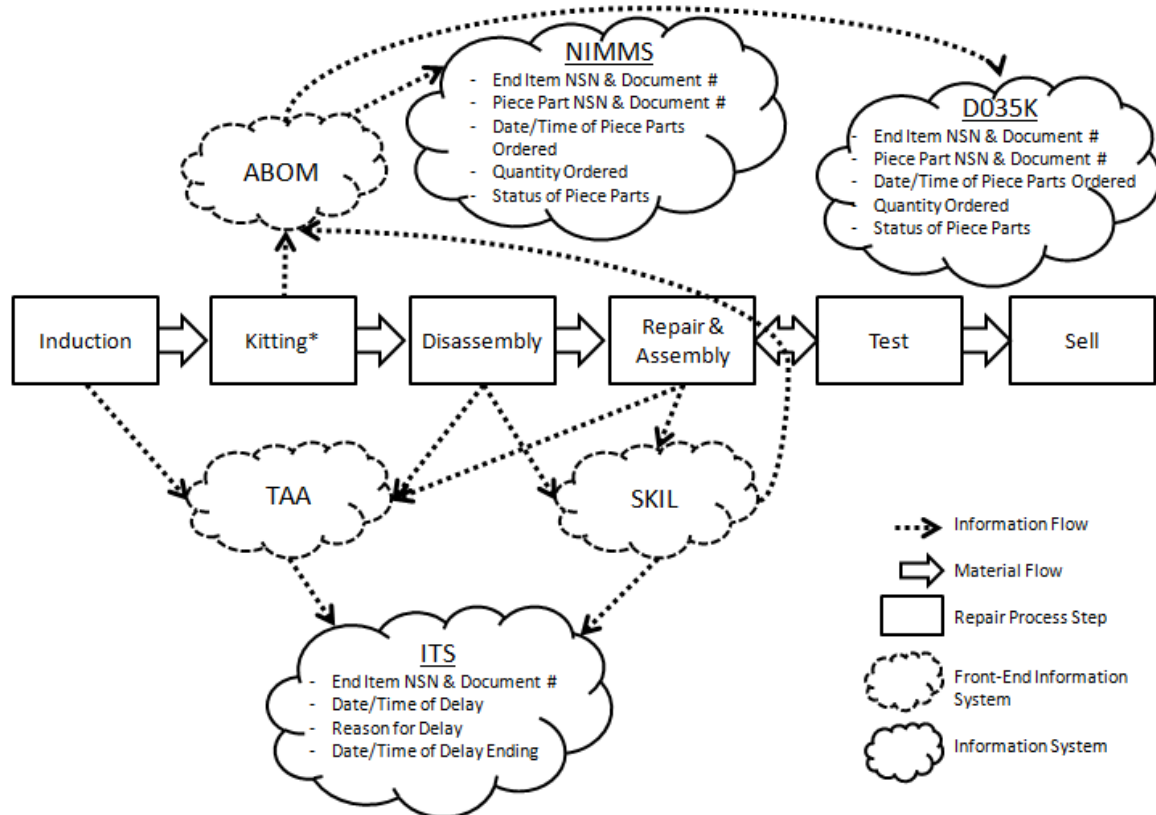
Figure 8. Fuels Accessories Shop Repair Process Flow Chart (Current State)

The repair process in the fuels accessories shop starts with end items needing repaired being "pushed" to the shop by EXPRESS. EXPRESS makes this determination based on many variables including demand from the field and piece parts availability. See section 2.2 for a more detailed explanation of the induction logic EXPRESS uses. If all requirements are met, then the end item is "pushed" to the shop for repair. Upon receipt, the scheduler inducts the end item. The scheduler prints a Work Control Document (WCD), which has three bar codes on it for each step in the repair process: Start, Complete, and Delay. The scheduler scans the Start bar code, which is recorded in the Time, Attendance, and Accountability (TAA) system.

TAA's primary purpose is to maintain accountability of worker's hours, time spent on each step, and other miscellaneous purposes. The information recorded via the Time, Attendance, and Accountability system feeds into multiple other systems, including the Inventory Tracking System (ITS). Only certain pieces of information recorded through the Time, Attendance, and Accountability system are sent to each of the other systems. The information pertinent to this research is not stored in the Time, Attendance, and Accountability system; therefore, it is considered a front-end information system where the pertinent information is entered by the technician, but stored elsewhere. In this case the pertinent information (starts, completions, and delays) is stored in the Inventory Tracking System.

Once the scheduler has inducted the end item, he/she scans Complete if a mechanic is available with the proper skill set. Otherwise, the scheduler scans the Delay bar code. If the Delay bar code is scanned, the scheduler must enter a delay code. A drop down menu of the delay codes appears on the screen in the Time, Attendance, and Accountability system. There are more than a dozen delay codes that can be entered, which cover a wide variety of reasons for delays. Most of the time, at this step, the scheduler selects the R01 delay code, which indicates that work cannot continue on the end item because the personnel or skill set needed is unavailable.

After induction, approximately 75-80% of end items move on to the Kitting step where any piece parts with an 80% probability of needing replaced are ordered. The end item does not leave Kitting until all ordered piece parts have been received. As a result, this is the first step where AWP delays can occur. The Kitting step was added by the 76th Commodities Maintenance Group to prevent end items with historically long AWP

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delays from clogging up the repair process. This is necessary because the depots do not control the flow of end items into their shops. EXPRESS dictates what gets repaired and what doesn't. The Kitting step is an effort by the 76th Commodities Maintenance Group to minimize queues in the repair process. However, it appears this step simply shifts the location of the queues into the Kitting step because end items in Kitting do not receive a higher priority than any other end items in the repair process, unless it is put through the formal AWP process. The priority of an end item is based on its priority to the customer, regardless of where it is in the repair process. However, if there are extra setup costs or time associated with starting repair work and then stopping repair work due to an AWP delay, this would result in a shorter flow time by putting the end item through the Kitting step. The researcher did not see any indication of significant extra setup costs or time in this shop. However, this could not be verified as it was not the focus of the research.

In the Kitting step, the piece parts are ordered in the Automated Bill of Materials (ABOM) system. The Automated Bill of Materials system is another front-end system where information is entered by the technician, but stored elsewhere. The information entered in the Automated Bill of Materials system feeds into the Navair Industrial Material Management System (NIMMS), where it is stored. NIMMS is primarily a financial accounting system, so the Air Force can account for the materials used to repair end items. However, it also communicates with the D035K, Wholesale and Retail Receiving and Shipping (WARRS) system, which is one of the supply systems used by the Air Force (Air Force Materiel Command, 2006: 52). As a result, the information entered in the Automated Bill of Materials system is stored in two information systems (NIIMS and D035K). The time an end item spends in the Kitting step is not recorded

through the Time, Attendance, and Accountability system as it is in the Induction step. However, the time an end item spends in the Kitting step can be captured by measuring the difference between the time Induction was completed in the Time, Attendance, and Accountability system to the time Disassembly was started in TAA.

The next step is Disassembly. For any end items that do not go through Kitting, Disassembly is accomplished right after Induction. In this step, end items are disassembled, cleaned, and inspected. Just as with the scheduler, the mechanic uses the three bar codes on the Work Control Document to record starts, completions, and delays in the Time, Attendance, and Accountability system throughout this step. During this step, repair or replace determinations are made for piece parts. If a piece part needs to be replaced, the order is placed in SKIL (Scheduling and Kitting Inventory Listing) by the mechanic. SKIL is a system created by and used only at Tinker AFB. It communicates with multiple other information systems, including the Automated Bill of Materials system, which is why piece parts are ordered through the Scheduling and Kitting Inventory Listing. If piece parts are backordered in this step, it does not delay the end item. The end item will be moved on to the Repair and Assembly step regardless of the status of piece parts ordered.

The end item then moves to the Repair and Assembly step. At this time, mechanics begin repairing or replacing piece parts as necessary and assembling the end item as they progress through the repairs. Again, the Time, Attendance, and Accountability system is used to record the starts, completions, and delays throughout this step. This is the second and final step where AWP delays can occur. If the mechanic does come to a work stoppage because the part or parts needed are not available, he/she

scans the delay bar code and enters the appropriate delay code. In some cases, the parts

may not be available because status on them has not yet been received. This most often

occurs early in the step when orders have just recently been placed. The delay code for

this scenario is R05. However, if the mechanic finds out that the part(s) needed is

backordered, the R06 delay code is selected. Therefore, the start of AWP delays are

already captured using the R06 delay code.

The end item is then set aside and the mechanic will begin work on other end

items. The exception to this is if the end item needs to be placed in formal AWP. There

is a separate process where end items can be placed in formal AWP status, which gives

the parts backordered for that end item a higher priority over end items that are not in

formal AWP. If an end item is put into formal AWP status, then it is removed from the

shop and locked in a cage controlled by the supplier (the Defense Logistics Agency in

most cases). The end item stays in that cage until all backordered parts are received. It is

then brought back to the shop. Whether in formal AWP status or just set aside in the

shop, the R06 delay code stays in effect until a mechanic scans in another status, which

could be Start or Delay with a different delay code selected. In some cases, the mechanic

identifies parts that need replaced and were not ordered in the Disassembly step. This

could be a result of an oversight, a defective part was received, the part was damaged

during installation, etc. Regardless of the reason, the piece part needed is ordered

through the Scheduling and Kitting Inventory Listing system, just as it is done in the

Disassembly step.

Once all repairs are completed, the end item is moved to the Test step. This is

where all end items are tested. If any end item fails during the Test step, personnel in the

Test step send it back to the Repair and Assembly step for the necessary corrective

action, then sent back to Test. As a result, no AWP delays can occur in the Test step. If

a piece part is the cause of a failure in the Test step and needs to be replaced, the end item

is sent back to the Repair and Assembly step for the necessary repairs. This process is

repeated until the end item passes the Test step. Finally, the end item is "sold" to the

customer.

4.3.2   Governors and Accessories Shop

The second shop visited was the Governors and Accessories Shop. For the sake

of brevity, the entire process will not be described. The process followed in this shop is

very similar to the Fuel Accessories Shop, so only the exceptions to the process described

in section 4.3.1 will be detailed here. Figure 9 depicts the repair process followed by the
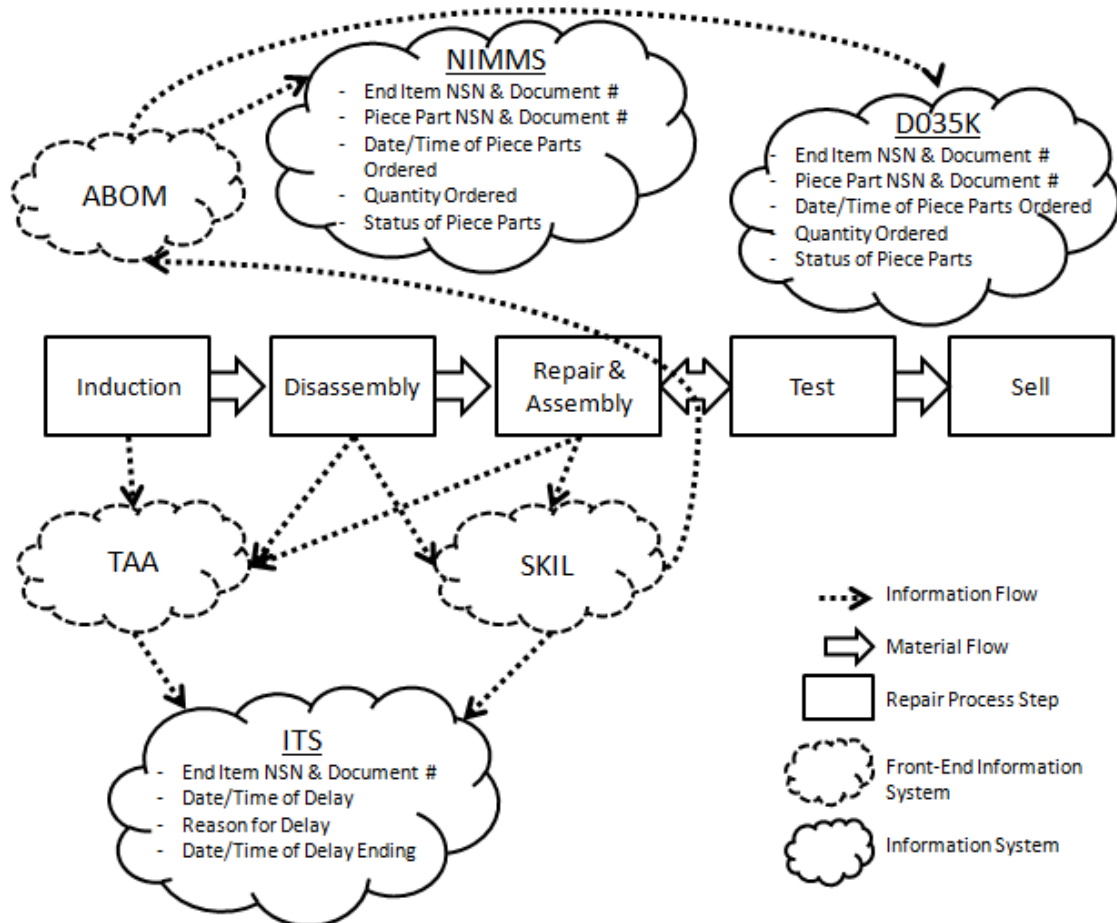
Governors and Accessories Shop.

Figure 9. Governors and Accessories Shop Repair Process Flow Chart (Current State)

Induction is accomplished just as described in section 4.3.1, to include using the same information systems. However, the Kitting step is not accomplished for any end items repaired in this shop. It is being discussed as an option for this shop, but has not yet been implemented. The Disassembly and Repair and Assembly steps are accomplished in the same manner as described in section 4.3.1, with one exception. If any piece parts are backordered, the end item is immediately put through the formal AWP process. The R06 delay code is still entered in the Time, Attendance, and Accountability system, so the AWP delay is recorded. The reason for this practice is due

to the long waits commonly experienced for backordered piece parts in this shop. There are no noteworthy differences for the Test and Sell steps.

4.3.3 Constant Speed Drives (CSD) Shop

Again for the sake of brevity, only exceptions to the process described in section 4.3.1 will be discussed. Figure 10 shows the current state of the repair process for the Constant Speed Drives shop.
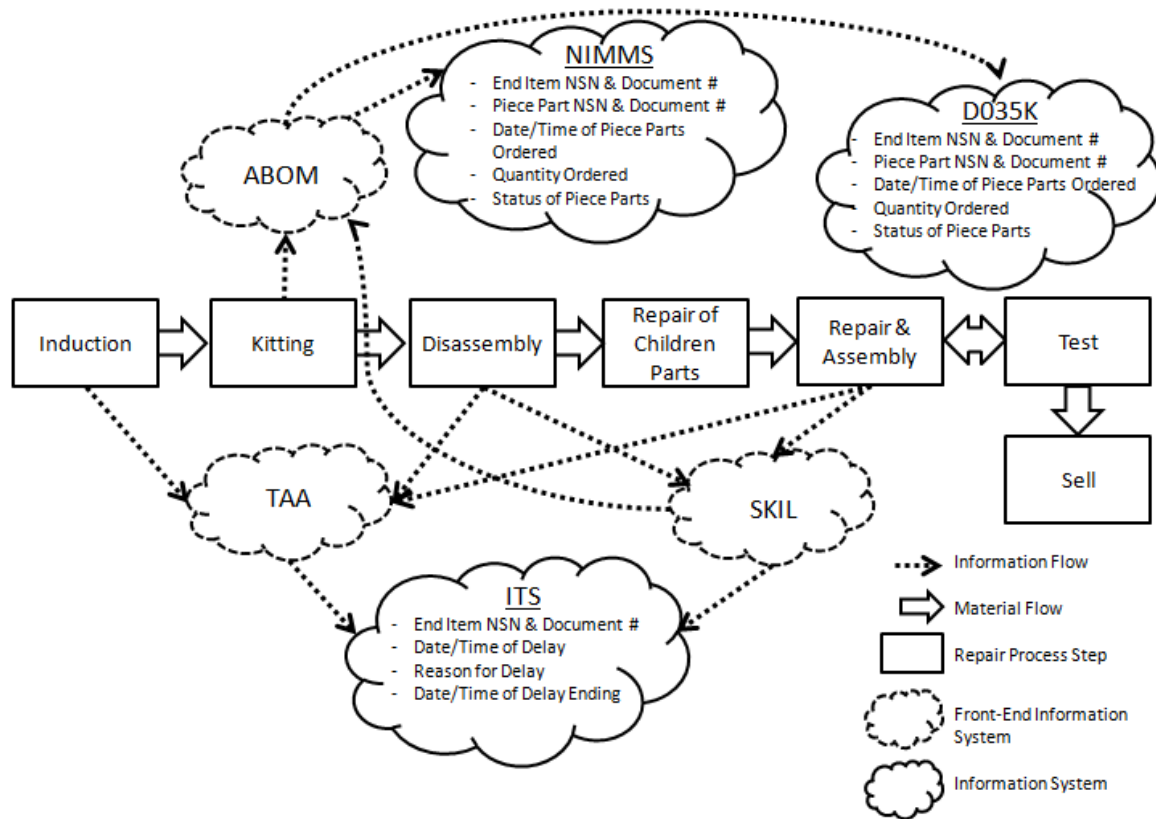

Figure 10. CSD Shop Repair Process Flow Chart (Current State)

The first difference of note is that Kitting does not have an asterisk next to it. This is because all end items repaired in the Constant Speed Drives shop go through the Kitting step. This is done because of the historically long AWP delays. It is also worth reiterating that the delays experienced in the Kitting step are not recorded in the Time,

Attendance, and Accountability system. There are no differences in the Disassembly step. Due to the nature of the end items repaired in the Constant Speed Drives shop, subassemblies (children parts) of the end items are sent to other shops in the Oklahoma City Air Logistics Complex. These subassemblies are only repaired in the other shops and do not have piece parts replaced in them, except those manufactured by the shops. In other words, if a piece part needs to be replaced, it is fabricated in that shop and is not dependent on an outside source of supply. Once all repairs are completed, the subassemblies are returned to the Constant Speed Drives shop. After all subassemblies are returned to the CSD shop for an end item, the Repair and Assembly step is started. This step and all remaining steps are performed as described in section 4.3.1.

4.3.4   Overall Repair Process

To simplify the gap analysis, these three shops' processes were generalized and combined into one overall repair process, depicted in Figure 11.
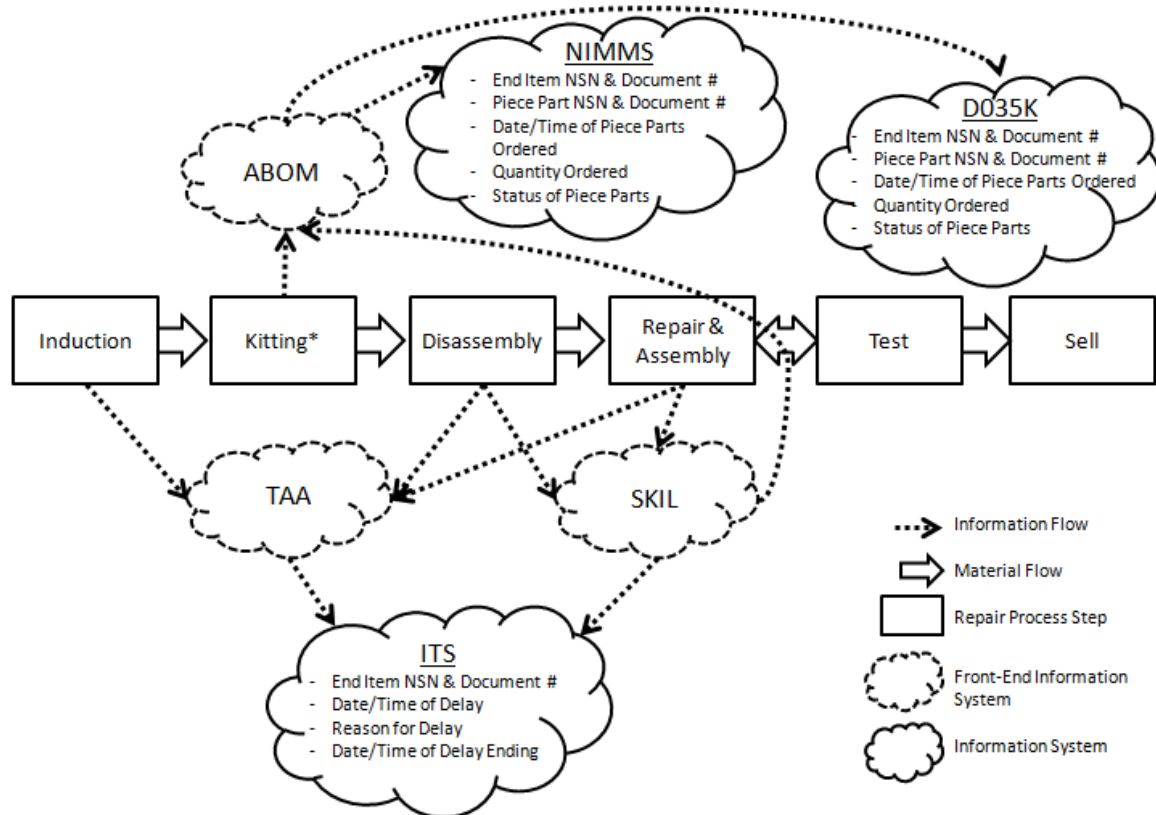
Figure 11. Overall Repair Process Flow Chart (Current State)

The process flow chart in Figure 11 is the same as depicted in Figure 8. This is possible because the Kitting step has an asterisk next to it indicating that not all end items process through the Kitting step, which is still a true statement. The Repair of Children Parts step from the Constant Speed Drives shop was removed from the flow chart because it can just as easily be explained as a sub-step within the Repair and Assembly step.

The locations of possible AWP delays in the repair process are identified in Figure 12.
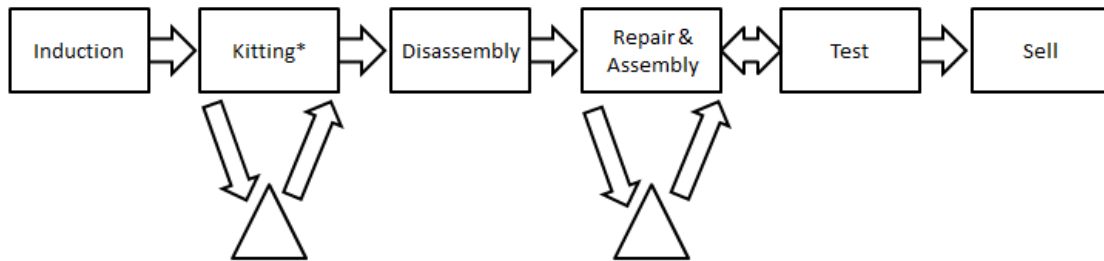

Figure 12. Possible AWP Delays

4.2.5 Desired End State

The desired end state should enable the creation of a list of piece parts that cause AWP delays. Since there are only two steps in the repair process where AWP delays are possible, the information regarding AWP delays would only need to be recorded in those two steps. In addition, this information should be recorded in one information system to ensure ease of use. The information included in this list based on the variables identified in section 4.2. First, the National Stock Number (NSN) of the piece part should be recorded any time it causes a delay, so that the part can be uniquely identified. Second, the piece part document number should be recorded, so the order for the piece part can be uniquely identified. Third, the end item national stock number should be identified anytime it is delayed. Fourth, the end item document number should be recorded, so each delay can be uniquely identified. Fifth, the start and stop time of the delay, by piece part document number and end item document number, should be recorded, so the total AWP time for that specific delay can be calculated.   Sixth, the quantity ordered should be recorded, so the magnitude of the shortage can be considered. Seventh, the frequency

needs to be recorded and can be calculated based on the information already listed above. Eighth, the sell price of the delayed end item needs to be recorded. Ninth, the purchase price of the piece part causing the delay should be recorded. Finally, the Spares Priority Release Sequence priority associated with the end item delayed needs to be recorded. This information should be recorded wherever an AWP delay can occur. Figure 13 shows the desired end state of information that should be recorded in the applicable steps. Kitting is shown with an asterisk to indicate that not all end items are put through the Kitting step.
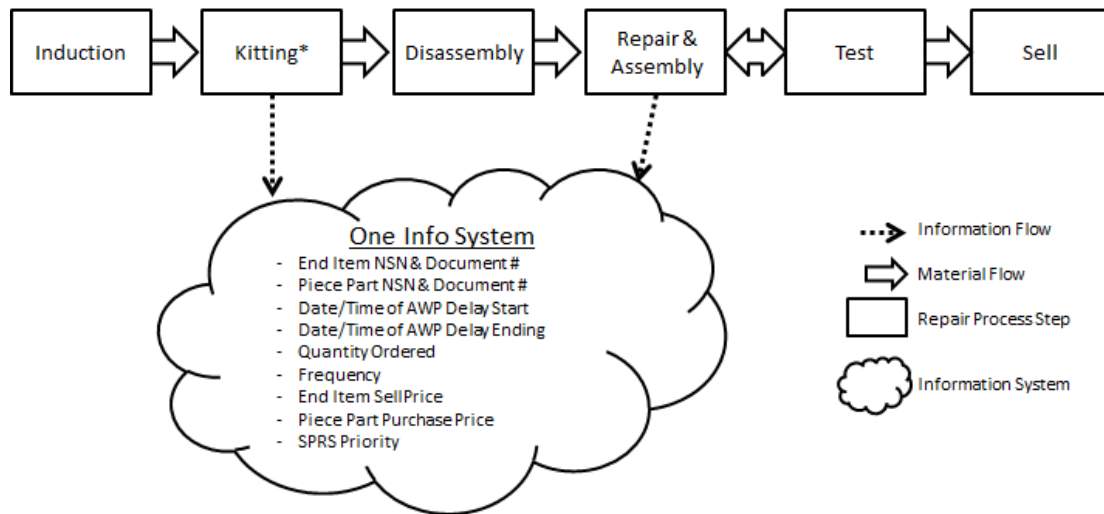

Figure 13. Desired End State

4.2.6   The Gaps

With the desired end state and the current state of the repair process defined, the gaps can be identified. In this gap analysis, the only gaps applicable are with regard to AWP delays. Therefore, only two steps need to be examined for gaps: Kitting and Repair and Assembly. To simplify the comparison, the six information systems currently used

to record and/or store data regarding AWP delays were consolidated into one depiction. In Figure 14, this consolidated depiction is labeled "Current State" and it is shown below the "Desired End State" information requirements. This allows for a direct comparison of the current state of information being recorded and the desired state of information recorded.
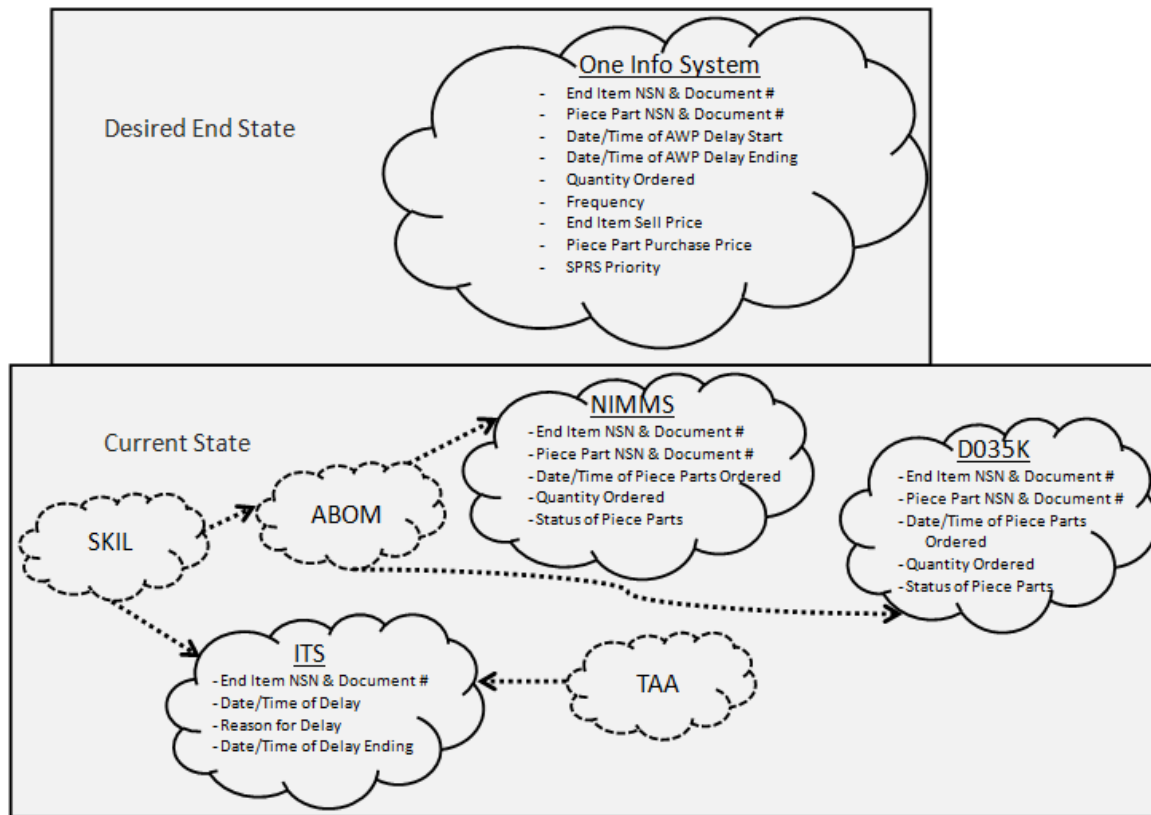

Figure 14. Comparison of Current State and Desired End State

Overall, it appears that most of the required information is already being recorded. However, the end item sell price, piece part purchase price, and Spares Priority Release Sequence priority are not recorded in the information systems identified in Figure 14. It also appears that the frequency is not currently recorded, which is partially correct.

Figure 11, "Overall Repair Process Flow Chart (Current State)," shows that the frequency of delays can be determined for any end items that experience an AWP delay in the Repair and Assembly step because every delay is recorded and an AWP delay is recorded as an R06 delay, which indicates the delay was due to parts unavailability.

In addition, each end item that processes through the Kitting step is, by definition, experiencing an AWP delay, so the number of end items processing through the Kitting step indicates the frequency of AWP delays. However, in the Kitting step, the start and stop time of any piece part causing a delay can only be ascertained based on the date/time a piece part officially goes into and out of a backordered status in the Navair Industrial Material Management System or the D035K system. This does not capture the time between a piece part not being available in the shop and it being placed into backorder status. Also, it does not capture the time between a part coming out of backorder status and the part physically arriving in the shop. It is a subtle difference, but can account for as little as one day or ten days. Therefore, its impact is of practical significance.

Both states in Figure 14 show that AWP delays are being recorded. However, in the current state, the delay is not directly attributed to the piece part(s) causing it. The cause of the delay can be ascertained by searching in the Navair Industrial Material Management System or the D035K system for the piece parts that were backordered at the time of the delay. Without linking the delay to the specific piece parts causing it, the list of piece parts causing delays cannot be created.

In addition to the comparison of **what** information is recorded in the two steps, there must also be a comparison of **where** the information is recorded. In the desired end state, all information about AWP delays is recorded in one information system.

However, as shown in Figure 14, the information is being recorded in six different information systems. Specifically, in the Kitting step, the information is being recorded in the Automated Bill of Materials system, which feeds into Navair Industrial Material Management System, which also feeds into the D035K system. From a practical perspective, the information is available in the Navair Industrial Material Management System and the D035K system since the Automated Bill of Materials system is only a front-end system and no information is stored in ABOM. The information recorded in the Repair and Assembly step is stored in the Inventory Tracking System through the Time, Attendance, and Accountability system. TAA does not record and maintain the information of interest to this research; it is another front-end information system. As a result, the AWP delays are being recorded in Navair Industrial Material Management System, the D035K system, and the Inventory Tracking System instead of just one information system. This means that even though most of the necessary information is currently being recorded, it is difficult to access it from three information systems. This was the biggest gap identified.

V. Conclusions

5.1 Overview

The intent of this research was to develop a process for creating a prioritized list of piece parts that are having the greatest negative impact on depot operations, in addition to developing a measurement (metric) by which depots could prioritize that list of piece parts. Based on the results discussed in Chapter 4, such a list is possible through two methods. The first method requires only minimal changes to the information recorded currently and could be implemented within six months. The second method would also require only minimal changes to the information recorded, but would require substantially more time and money for software programming (roughly 4-6 years). The analysis of the AWP Impact Index indicates that it does produce priorities that are significantly different from its individual variables, except AWP time. However, further research and development of the metric is needed, so the metric should be used only on a limited basis. Finally, opportunities for future research related to this topic are discussed.

5.2 Developing the Piece Parts List

At first glance, the necessary information is not available to develop a prioritized list of piece parts causing AWP delays. However, to develop the list, one has to consider the sources of the information needed. Who/what would have information on AWP delays in the repair process? The results show that AWP delays can only occur in the Kitting step or the Repair & Assembly step. Therefore, the individuals performing the tasks in those steps are the information sources for the delays.

5.2.1   Option #1

Currently, nothing performed in the Kitting step is recorded in the Time, Attendance, and Accountability system. To be consistent with the other steps of the repair process, personnel in the Kitting step should record Starts, Completions, and Delays in the Time, Attendance, and Accountability system. This would also allow the depot to capture ALL of the AWP delays in one information system. If technicians in the Kitting step enter the R06 delay code in the Time, Attendance, and Accountability system when they place orders for piece parts, then the actual start of the delay time could be captured. Next, the end of the delay time by piece part needs to be captured. In the Kitting step, technicians determine which piece parts have an 80% or greater probability of needing replaced. The technicians then enter the orders for those parts in the Automated Bill of Materials system, which feeds into Navair Industrial Material Management System and the D035K system. As a result, a list of parts necessary for repair of the end item is in the D035K system. However, the only parts of interest are the ones not available to the technicians. In other words, backordered piece parts are the only parts of interest. The end of the delay time for each piece part can be captured by recording when the piece part's status in D035K changes from backordered (BB, BC, BD, or BI) to any other status code (Air Force Materiel Command, 2007: 118-119).

For the Repair & Assembly step, the information source for AWP delays is the mechanics working on the end item. In this step, the mechanics already record when an AWP delay occurs. They record the delay in the Inventory Tracking System via the Time, Attendance, and Accountability system with an R06 delay code. However, they do not currently record which parts caused the delay. Logically, they should not be waiting

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on any parts that are already available; therefore, they should only be waiting on parts that are backordered. The backordered parts for the end item will be in D035K. There are exceptions to this scenario. For example, the necessary parts are in stock, but they have not yet arrived from their storage location. In addition, a part could have been initially backordered, fulfilled, but still be in transit from the supplier. However, even in these scenarios, the technician is still at a work stoppage and that fact should be captured. The event may get recorded as zero delay time, but would still be recorded as an instance of a work stoppage. Also, one has to keep in mind the purpose of the parts list. It is meant to be used for root cause analysis and problem solving efforts, so the scenarios described would still need to be considered in any problem solving effort.

So far, it has been shown that the information on delays is available, or could be with only minor changes to the Kitting step. The next problem to be solved is how to access and sort the information. Based on discussions with the information system offices of primary responsibility (OPRs) and programmers at Tinker AFB, it appears that Cognos 8 could retrieve and sort the desired information. Cognos 8 is "a SQL report writing tool that can access data from one or more databases and is the Air Force standard for reporting tool" (Grilley, 2013). Cognos should be able to query the Inventory Tracking System for any end items that have an R06 delay code loaded against them. The R06 delay code indicates an end item is at a work stoppage because it is awaiting parts. Then, Cognos could query D035K for the parts backordered against those end items. The Cognos report would then be able to display the total delay time across the 76th Commodities Maintenance Group by piece part. In addition, the report could

display the frequency of delays by piece part, and the total quantity ordered, which is all available in the Inventory Tracking System and D035K.

In order to use the AWP Impact Index, Cognos would also have to collect data on the end item sell price, piece part purchase price, and the Spares Priority Release Sequence priority. The end item sell price is available in the Job Order Production Master System (JOPMS), which is a "repository for storing the production number master records" (Goodman, 2013). The piece part purchase price and Spares Priority Release Sequence priority are available in EXPRESS. Therefore, Cognos would have to cross-reference the list of end items and piece parts pulled from the Inventory Tracking System and the D035K system, with the Job Order Production Master System and EXPRESS to gain the necessary data for the cost ratio and Spares Priority Release Sequence priority, as shown in Figure 15. Figure 15 shows how Cognos can match end item national stock numbers and document numbers and piece part national stock numbers and document numbers across information systems to pull the necessary data and compile it in a format defined by the user. This has the same effect of all the information being stored in one information system. As a result, the list could then be prioritized using the AWP Impact Index or any of its variables.
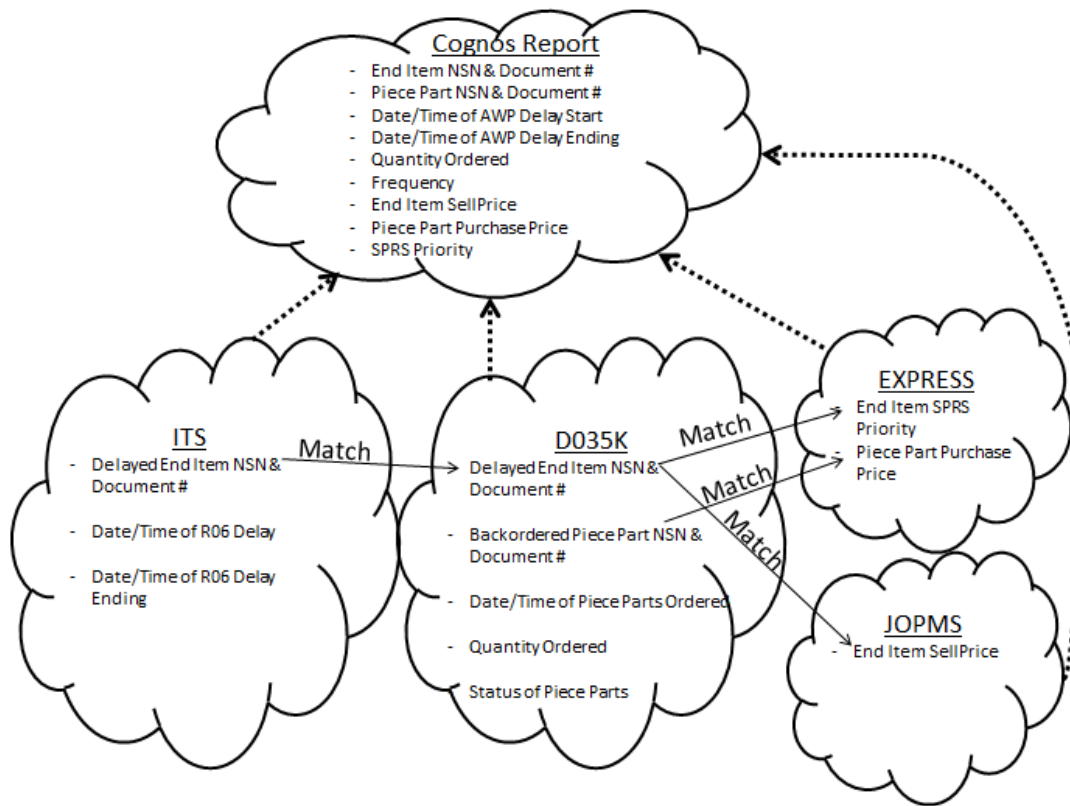
Figure 15. Option #1 Method of Retrieving Data

However, such a report would present all parts backordered at the time of the

delay. This is useful for providing a snapshot of the current delays, so that managers can

determine which parts are most needed at that particular moment. Based on the expert

panel's recommendations, only the last piece part to come in, thus ending the delay,

should be recorded as the cause of the delay (see section 4.2.2). This could be

accomplished by applying a logic function that only records the piece part with the most

recent status change date or the longest delay time per occurrence. However, this method

can only be fully applied when taking a historical view of the data. For example, one

could pull a Cognos report that displayed data for all end items sold in 2012, regardless

of the induction date. This would exclude any end items that are currently delayed, but it would allow the user to attribute each delay to only one piece part. Otherwise, if a report was pulled that displayed all end items currently in the repair process (meaning they have been inducted, but not sold), each end item that is delayed could have multiple piece parts backordered against it at the time of the report, thus making it impossible to attribute each delay to only one piece part. This is not necessarily a problem. It is simply a fact that must be considered when requesting Cognos reports to ensure that the user gets the proper data reported.

5.2.2   Option #2

A second option is more costly in time and money, but more accurate. Just as in the first option, technicians in the Kitting step would have to start recording R06 delays in the Inventory Tracking System via the Time, Attendance, and Accountability system. However, if the programming money could be acquired, two features could be added to the Time, Attendance, and Accountability system to allow a more detailed recording of AWP delays. First, whenever the R06 delay code was selected in the Time, Attendance, and Accountability system, another window should appear, which requires the technician to select which part(s) from the bill of materials is causing the work stoppage. Then, whenever the technician scanned the Start bar code again, if it was in Delay status with an R06 delay code, the bill of materials window should appear again to require the technician to select which part(s) allowed them to begin work again. This would be repeated anytime the technician experienced an AWP delay. If that information was recorded in the Time, Attendance, and Accountability system, then it would feed into the Inventory Tracking System and all the data needed to identify and track AWP delays

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would be available in the Inventory Tracking System. Just as described in section 5.2.1,

a Cognos report would need to pull the necessary data from the Inventory Tracking

System, Job Order Production Management System, and EXPRESS, in order to prioritize

the parts list by the AWP Impact Index or any of its variables. However, in this option,

Cognos would not have to query the D035K system for any information because it would

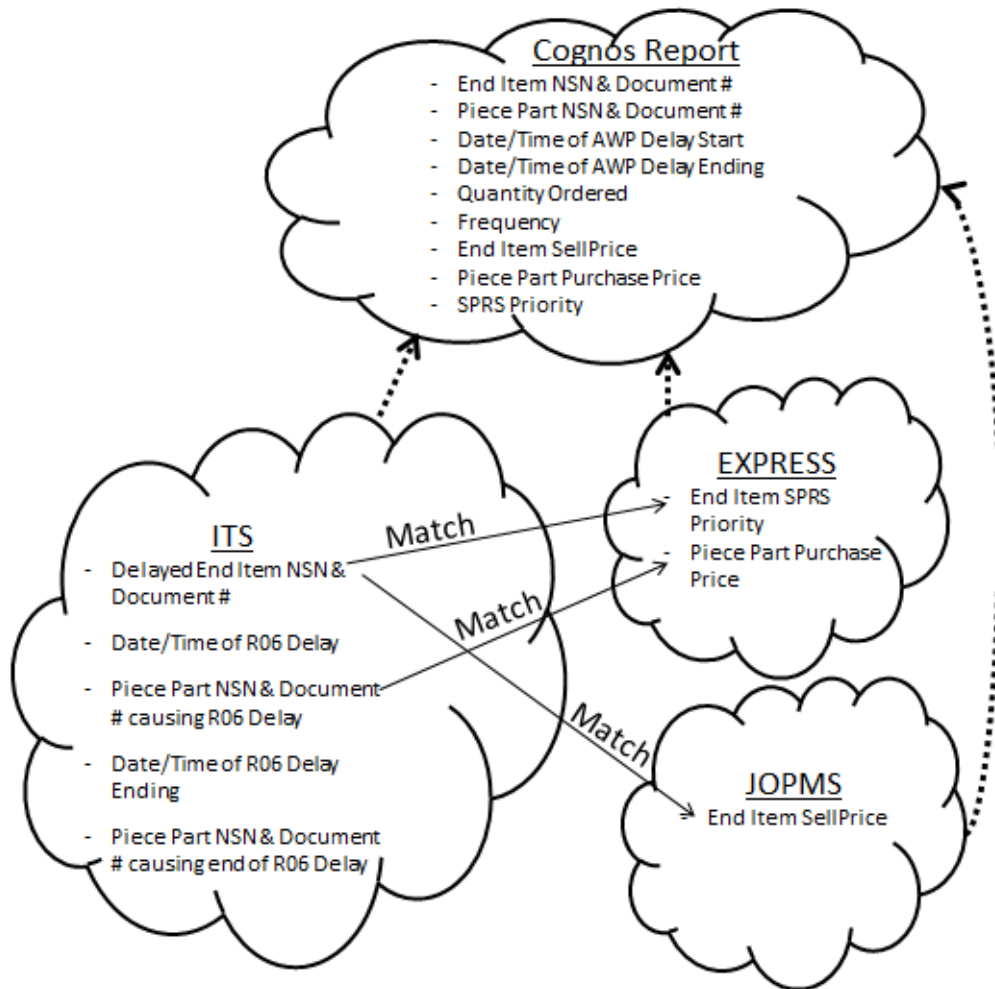be contained in the Inventory Tracking System, as depicted in Figure 16.

Figure 16. Option #2 Method of Retrieving Data

5.2.3 Which Option is Better?

Each option has its limitations. First of all, both options rely on human input. As a result, the reliability of the information is not perfect. Some common errors known to occur are: entering the wrong delay code, not recording the delay at all, or entering the delay at the wrong time. The most common error, based on discussions with technicians, work leaders, and schedulers is entering the wrong delay code. Technicians use certain codes more commonly than others, so they will sometimes enter a code that they use quite often instead of determining the correct code to select. This is a significant threat to reliability, but can be mitigated by training and supervision. In addition, most of these errors will underreport AWP delays. There are no indications that this error would occur more frequently on certain end items, which means that the error should be independent of the end item. This error would result in lower AWP delays on all parts, but would probably not have a major impact on the rank-order of the parts list. Of course, until real data is collected, this argument cannot be tested.

A limitation unique to option #1 is the fact that the delay time recorded would not be the total delay time. The exact moment the end item comes to a work stoppage is recorded with the R06 delay code. However, recording when the piece part is no longer backordered does not provide the exact time the work stoppage ended. In actuality, the work stoppage is ended when the technician can begin work on the end item again. When a part is no longer listed as backordered, it simply means that a part has been located to satisfy the order. The part could be in transit for several days. This reduces the reliability of the data. By definition, this underreports the AWP delay time. In addition, the transit time for certain parts could be consistently longer or shorter than

other parts' transit times depending on the location of the supplier. As a result, it could affect the distribution of the data and the rank-order of the parts list. However, the transit time per part is typically much shorter than the overall delay time on many AWP parts. It is not uncommon to wait six months, twelve months, or even eighteen months for some parts. In addition, the average transit time (from supplier to depot) across all piece parts could be added to each delay, thus eliminating any biased error. Thousands of parts are ordered every day for the Oklahoma City Air Logistics Complex, so the law of large numbers works in our favor. In short, the impact of not including the transit time from the supplier to the depot is deemed to be minimal, especially if the average transit time is added to each delay.

A limitation unique to option #2 is that it relies on human input for the start and stop time and the parts causing the delay. If the information is recorded correctly every time, option #2 is much more accurate than option #1. Option #2 allows for human error on four pieces of information, whereas, option #1 only allows for human error on one piece of information.

Reliability and validity of the measurement aside, there are practical limitations to be considered. Option #1 is estimated to take six months or less to implement. Its cost is not yet known, but the Cognos programmers were able to confidently state that it would be significantly cheaper than option #2. In addition, option #2 is estimated to take four to six years to implement. The applicable information systems offices of primary responsibility (OPRs) and programmers at Tinker AFB provided the time and cost estimates.

Due to the high cost and long lead time of option #2, the author recommends that option #1 be implemented, unless the increased accuracy of option #2 is deemed necessary by the users. Option #1 provides relatively accurate information and it can be made available in a much shorter period of time at a much lower cost. However, the average transit time should be added to each delay to increase the accuracy of Option #1 and to avoid any biased error. Especially given the tight fiscal situation, option #1 seems the prudent choice. The data is aggregated, so the error that is inherent in option #1 should not have a major negative impact on decisions made from it. The main argument against option #2 is the enormous cost of just gaining the capability of collecting the necessary data, without knowing exactly what benefit will be gained from it. Hand argues that "…if the aim of measurement is to lead to an improvement of some process, one must be certain that the cost of taking that measurement does not outweigh the gains to be made through knowing it" (Hand, 2004: 23). He goes on to emphasize that this is particularly applicable in "managerial and governmental contexts" (Hand, 2004, 23). In short, if option #2 is selected for implementation, it would best to know precisely what benefit can be gained from the increased accuracy it offers, so a proper cost-benefit analysis can be conducted.

5.3   Prioritization Recommendations

Using only one variable to prioritize piece parts ignores the other important variables. Therefore, the goal was to combine the important variables in such a way that a significantly different prioritization is created that considers all important variables. The results show that, overall, the AWP Impact Index prioritization of piece parts is significantly different, except when compared to the AWP time prioritization. The

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correlation between the index and AWP time was not extremely high ($r_s = 0.65$). In addition, this could be overcome by adjusting the weights assigned to the variables. Regardless of the weights chosen, subject matter experts should examine the prioritizations carefully to determine their correctness.

Another potential limitation of an index equation defined as a linear, additive relationship of its constituent variables is that such equations can give inconsistent results for other measures when they are in-turn defined as products or quotients of the original index equation variables. Table 8 illustrates this. Note that each of the weights and variable values are normalized before computation. Suppose that an AWP impact index equation is defined as the weighted sum of Frequency and Average Time, and further suppose that a new measure *Total Time* is introduced, where Total Time is defined as the product of Frequency and Average Time. In this scenario each part has the same Total Time value and thus a ranking computed only from the Total Time measure should result in a tie for piece parts A, B, and C. However, Table 8 shows that the AWP impact index equation ranks each piece part differently, in a strict priority order.

A final insight on variable values and weights can also be gleaned. In this extreme-valued scenario, the weight assigned to Frequency must be more than 100 times larger than the corresponding Average Time weight to prioritize the parts by frequency as A, C, and then B. However, decision makers may not know that they must sometimes first establish weights differing by several orders of magnitude, before attempting to use such weighted ranking schemes.   A better strategy for forcing an additive index equation to focus on only one or two of its constituent variables, would be to use zero-valued weights for the variables to be ignored, if computationally feasible.

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Table 8. AWP Impact Index Limitation Scenario

Weights	0.5	0.4	Total Time	AWP Impact Index
Piece Part	Frequency	Average Time		
A	1000	1	1000	0.556
B	1	1000	1000	0.445
C	10	100	1000	0.05

The primary recommendation is to further develop the AWP Impact Index. For example, a multiplicative equation could be attempted. Also, a further reduction of the variables may be beneficial. Frequency and quantity are highly correlated ($r_s = 0.90$), which means having both of them doesn't change the prioritizations much. Since frequency had the highest relative importance, quantity would be the logical variable to remove. Regardless of the modifications made to the index, analysis would still have to be conducted to determine if the prioritizations were significantly different. In addition, subject matter experts would need to examine the prioritizations to determine if they were correct.

If the index is used in its current form, the weights should be adjusted and the resulting prioritizations should be examined carefully. In addition, the index should only be used to narrow the list of piece parts. Subject matter experts should then limit the list further using their best judgment and intuition. The index should only be used to augment knowledge, experience, and intuition.

All four methods used to test the AWP Impact Index, tested for differences and commonalities. None of the methods indicate which measurement is best suited for prioritizing piece parts. Only the users of these measurements can determine which measurement gives the best prioritization. While the AWP Impact Index may not

produce the best prioritization, it should not be interpreted to mean only frequency should be used to prioritize piece parts since it is the highest priority. To do so would inherently ignore all other factors that drive the importance of a piece part.

5.4   Future Research Opportunities

This research only scratches the surface of the AWP problem. This research provides the capability to identify, track, and prioritize piece parts causing delays in the 76th Commodities Maintenance Group's repair process. The next logical step is to use this capability to conduct a root cause analysis of the piece parts with the highest impact. Such a study could identify major opportunities for cost savings, process improvement, and increase general awareness of the sources of AWP delays. In addition, this thesis only examined the 76th Commodities Maintenance Group. As a result, research could be done to determine the how or if AWP delays can identified, tracked, and prioritized in the other units at the Oklahoma City Air Logistics Complex and the other two Air Logistics Complexes.

In addition to expanding the scope and application of this research, the prioritization methods used could be further researched and developed. This research did not determine if the prioritization methods used produce correct prioritizations. A Delphi Study could be a useful tool for such research. Also, there are a number of inherent flaws with each prioritization method, so there is plenty of room for improvement. Such improvements could include determining a better way to combine the variables identified in this research, determining if different variables should be used, and determining how sensitive the measurements are to change.

While conducting this research, another AWP problem was identified. This thesis focused on AWP delays once end items are inducted into the ALC, but delays occur prior to their induction into the ALC as well. This was briefly mentioned in section 2.2. This problem was identified by Mr. Steve Roberts at Tinker AFB and he has made some progress towards addressing the problem. However, there remains much room for research and improvement (Roberts, 2013). In addition, if the data regarding piece parts causing end items not to be inducted could be combined with the data on piece parts causing delays inside the Air Logistics Complexes, it would provide a much more holistic view of the problem. This would greatly enhance the Air Force's awareness of the root causes behind its AWP delays. Such awareness is the necessary first step to solving those problems.

Questions about the effectiveness of the Kitting step in the repair process were raised in section 4.3.1. Based on a limited view of the Kitting step, it appears to only shift the queues from the Repair and Assembly step to the Kitting step. In addition, increased setup costs or time were not identified. As such, no direct benefit of the Kitting step could be seen. This received minimal attention in this thesis because it was not pertinent. However, research could be done on the effectiveness of the Kitting step in the 76th Commodities Maintenance Group as compared to other units. It is possible that the Kitting concept is not universally applicable to all types of shops or processes. Such research could either reinforce procedures currently in place or identify weaknesses in the current procedures. Either result would be of great benefit to the Air Logistics Complexes and contribute to the body of research on High-Velocity Maintenance.

5.5   Conclusion

When this research began, the goal was to compile a list of piece parts causing

delays in the Air Force's Air Logistics Complexes along with other pertinent information

regarding the delays, so that an in-depth analysis of the underlying causes of those delays

could be ascertained and addressed. It became apparent that such a lofty goal could not

be accomplished within the time constraints of this thesis. In addition, it became

apparent that even the most basic information about AWP delays was difficult to gather

on a large scale. The realization that followed was that the Air Force had been looking at

the problem from only one perspective. It had been examining the AWP problem from

the end item perspective. As a result, all of the information systems allowed for

summations by end item, but not summations by piece part. To be sure, one can hone in

on one end item and determine which piece parts it is consistently or currently waiting

on. However, no one interviewed throughout this research knew of a way to turn the

tables and find out which piece parts are causing delays. The Air Force's information

systems were designed to track data by end item, not by piece part.

This thesis identified two methods that will enable the Air Force to identify, track,

and prioritize piece parts. If implemented, this will allow the Air Force to take a much

more holistic view of the AWP problem. Instead of tackling the AWP problem one end

item at a time, it will be able to address systemic problems. It will bring a level of

awareness to the problem that has not yet been achievable. In addition, one of the

methods identified is a fiscally responsible option, which makes its implementation much

more feasible. It will not require modifications to any information systems and it will

only require a minor change to the way information is currently being recorded in the 76th Commodities Maintenance Group.

　　　　While this study did not produce an aggregate measure of AWP impact that is ready for use, it did initiate the conversation and thought regarding the subject. The measures created in this research are a first step to formalizing how AWP delays negatively affect depot operations. An enhanced understanding of these effects should prove useful to depot leadership in day-to-day decision making and in communicating the importance of minimizing AWP delays.

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Vita

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14. ABSTRACT

The Air Force is pursuing several efficiency initiatives designed to reduce support function costs. One such initiative is an effort to reduce the flow days of items being repaired in the Air Force's organic depots. Many end items are affected by awaiting parts (AWP) delays, which increase total flow days. The first step in reducing AWP delays is to identify which piece parts are causing the delays. A gap analysis was conducted to identify a process for creating a list of piece parts that are causing AWP delays. In addition, a clinimetric method was used to develop an aggregate measure of AWP impact by which the list of piece parts could be prioritized. The gap analysis showed that such a list can be created with Cognos, a reporting tool currently used by the depots, which can pull data from multiple information systems. In addition, only minor changes to information recorded throughout the repair process are needed. An aggregate measure of AWP impact was also created and tested. It produced significantly different prioritizations from the individual constituent variables, and provides a possible method for helping depot managers to understand decision tradeoffs between different parts shortage priorities.

15. SUBJECT TERMS
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